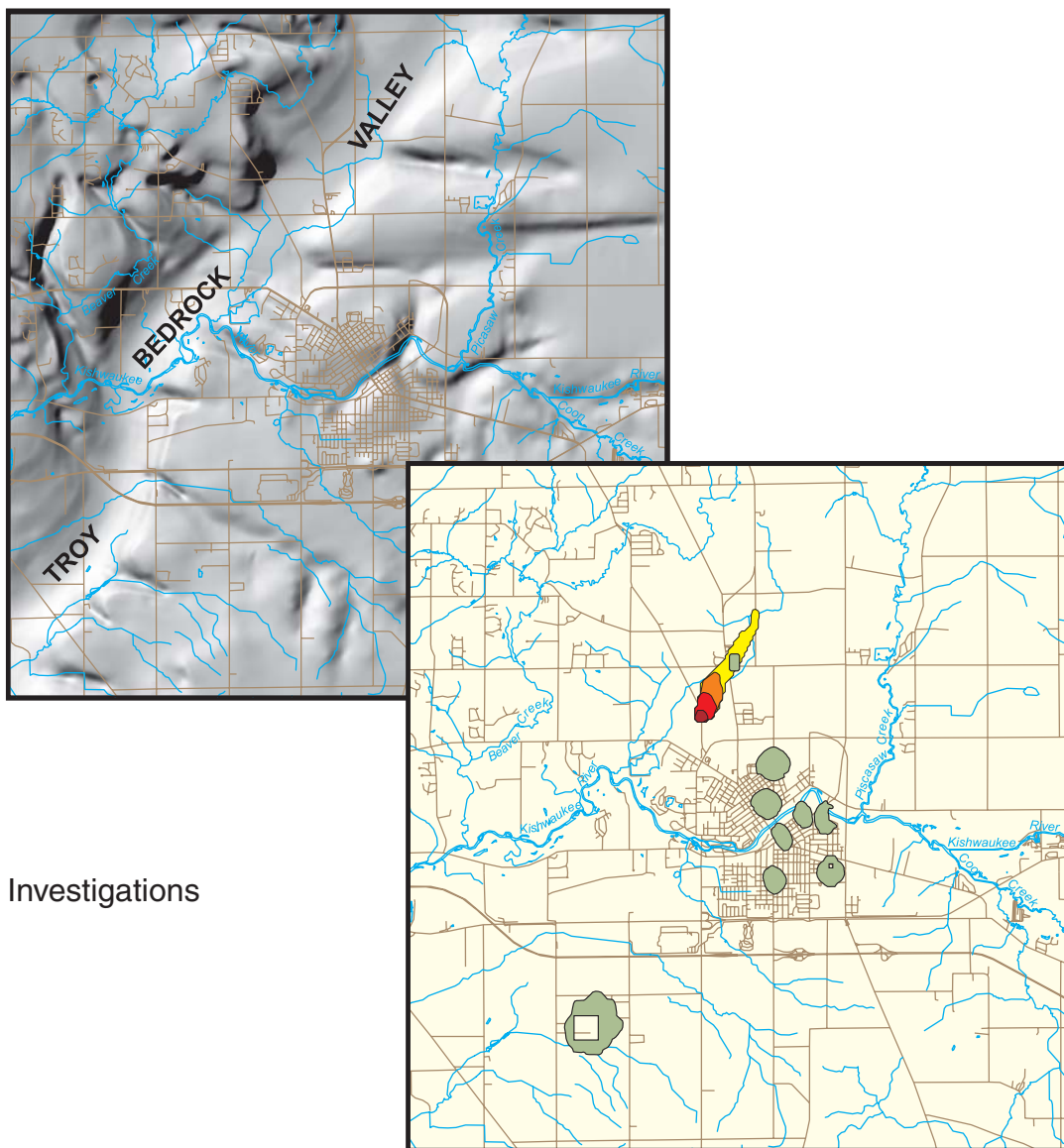


In cooperation with the Illinois Environmental Protection Agency
U.S. Environmental Protection Agency

Delineation of the Troy Bedrock Valley and Particle-Tracking Analysis of Ground-Water Flow Underlying Belvidere, Illinois



Water-Resources Investigations
Report 02-4062

U.S. Department of the Interior
U.S. Geological Survey

Delineation of the Troy Bedrock Valley and Particle-Tracking Analysis of Ground-Water Flow Underlying Belvidere, Illinois

**By P.C. Mills (U.S. Geological Survey), K.J. Halford (U.S. Geological Survey),
and R.P. Cobb (Illinois Environmental Protection Agency)**

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In cooperation with the
Illinois Environmental Protection Agency
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Urbana, Illinois
2002

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
Length		
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
Area		
square mile (mi ²)	2.590	square kilometer
Flow rate		
gallon per minute (gal/min)	3.785	liter per minute
million gallons per minute (Mgal/min)	3.785	million liters per day
million gallons per year (Mgal/yr)	3.785	million liters per year

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32$$

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Altitude, as used in this report, refers to distance above or below sea level.

Horizontal datum, used in this report is the North American Datum of 1927.

Abbreviated water-quality units used in this report: Organic- and inorganic-constituent concentrations, water temperature, and other water-quality measures are given in metric units. Constituent concentrations are given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter are considered equivalent to parts per million at the reported concentrations. Micrograms per liter are considered equivalent to parts per billion at the reported concentrations. Constituent concentrations given in the report are estimated if less than the reporting limit.

Estimated concentrations are indicated in appendixes 2-5.

Tritium concentrations are given in picocuries per liter (pCi/L) and tritium units (TU). Picocuries per liter may be converted to tritium units as follows:

$$\text{TU} = \text{pCi/L} \times 0.3125$$

Specific conductance (SC) of water is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm). The unit is equivalent to micromhos per centimeter at 25 degrees Celsius (µmho/cm), formerly used by the U.S. Geological Survey.

Dissolved oxygen (DO) is given in milligrams per liter (mg/L)

Oxidation-reduction potential (Eh) is given in millivolts (mv).

Turbidity is given in nephelometric turbidity units (NTU).

Delineation of the Troy Bedrock Valley and Particle-Tracking Analysis of Ground-Water Flow Underlying Belvidere, Illinois

By P.C. Mills, K.J. Halford, and R.P. Cobb

Abstract

The U.S. Geological Survey, U.S. Environmental Protection Agency, and Illinois Environmental Protection Agency began a study of the hydrogeology, flow system, and distribution of contaminants in the aquifers underlying Belvidere, Ill., and vicinity in 1992. As part of the study, the ancestral Troy Bedrock Valley, located about 1.5 miles west of Belvidere, was identified as an important part of the ground-water-flow system. In the deepest parts of the valley, the basal Glenwood confining unit may be absent; thick deposits of sand and gravel that infill part of the valley may directly overlie the sandstone St. Peter aquifer, a regionally important source of water for public supply. With few deep wells open to the St. Peter aquifer present in the valley to provide necessary geologic information, tritium and other water-chemistry data were collected from eight wells to possibly delineate areas where the confining unit may be absent; the data also provide baseline water-quality information for an area expecting changes in land use and increases in water withdrawal. Also as part of the study, particle-tracking analysis was done using an available flow model to (1) identify possible discharge locations of ground water and contaminants and (2) delineate areas contributing recharge to the Belvidere municipal wells.

This report presents and interprets water-chemistry data collected during December 2000 and presents results of particle-tracking analysis. Ground water in samples from two of four wells open to the St. Peter aquifer appears to have recharged after 1954, suggesting that the Glenwood confining unit may be absent near the wells. Other hydrogeologic and water-chemistry

data, however, were inconclusive or contradictory. Concentrations of iron, manganese, and lead exceeded maximum contaminant levels in five or less samples, but materials associated with the water-distribution systems appear to contribute to the elevated concentrations above natural levels.

Particle-tracking analysis indicates that most ground-water flow beneath possible contaminant-source areas discharges from the glacial drift aquifer to the Kishwaukee River. Most of the source areas are in or near Belvidere and are within 1,500 feet of the river. The analysis also indicates the possibility that in parts of the study area, some ground water does not discharge to the river, but flows beneath the Kishwaukee River in the underlying carbonate Galena-Platteville aquifer. Ground water that discharges to the one municipal well open to the glacial drift aquifer is estimated to travel over 1 mile in less than 25 years. Simulated residence (travel) times of ground water from the base of the glacial drift aquifer to the six municipal wells open, in part, to the Galena-Platteville aquifer, are estimated at less than about 40 years. Because fractures in this aquifer are unaccounted for in the flow model, actual areas contributing recharge are likely larger and travel times faster than those simulated for most of the municipal wells. Tritium data indicate that, in general, travel times from the land surface to the deepest parts of the Galena-Platteville aquifer are less than 46 years. Methyl *tertiary*-butyl ether data indicate that travel times to the upper part of the aquifer may be less than 16 years. The water-quality-based estimates of travel time generally are consistent with the estimates from particle-tracking analysis.

INTRODUCTION

Volatile organic compounds (VOC's) have been detected in water samples from at least 5 of 8 municipal and 13 private water-supply wells open to the glacial drift and bedrock aquifers underlying Belvidere, Ill. and vicinity (Brown and Mills, 1995; Mills and others, 1998, 1999) ([fig. 1](#)). Samples collected from monitoring wells installed adjacent to the Kishwaukee River at four locations indicate that VOC's may be discharging into the river (Roy F. Weston, Inc., 1988; Clayton Environmental Consultants, Inc., 1996; Mills and others, 1999). VOC's and other contaminants periodically have been disposed of at industrial and commercial facilities and at three regulated solid-waste landfills in the area ([fig. 1](#)). Presently (2001), one industrial facility and two landfills are Superfund sites on the U.S. Environmental Protection Agency (USEPA) National Priorities List established (in 1980) by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Superfund Amendment and Reauthorization Act of 1986 (SARA). Because ground water is the sole source of public-water supply for Belvidere's 18,000 residents and demand is expected to increase (Belvidere's population has increased about 18 percent since 1990 (Belvidere Area Chamber of Commerce, 2000)), ground-water-remediation and -protection efforts are a high priority.

In 1992, the U.S. Geological Survey (USGS), in cooperation with the USEPA, initiated a study of the hydrogeology and water quality of the aquifers underlying Belvidere and vicinity ([fig. 2](#)). The objectives of the study were to (1) determine the regional distribution and factors affecting the occurrence and distribution of contaminants in the aquifers, with emphasis on explaining the presence of VOC's in water withdrawn by the Belvidere municipal wells; (2) assess the effect of ground-water contamination associated with non-Superfund hazardous-waste sites on investigations and remediation options at Superfund sites; and (3) provide the necessary data and analysis to assist other agencies and organizations in developing strategies for remediation of ground-water contamination and protection of ground-water supplies of the area. During 1999-2001, in cooperation with the Illinois Environmental Protection Agency (IEPA) and USEPA, a ground-water-flow model was developed to evaluate the conceptual model of the flow system, estimate

water budgets within subsections of the study area, and identify parts of the study area where additional data may be necessary to properly describe the hydrogeologic framework of the flow system. The hydrogeology and water quality of Belvidere and vicinity and the ground-water-flow model are described in detail in Brown and Mills (1995), and Mills and others (1998, 1999, 2002).

The ancestral Troy Bedrock Valley, located about 1.5 mi west of Belvidere ([fig. 3](#)), has been identified as an important part of the ground-water-flow system that (1) may contribute substantially to recharge and possible future contamination of the underlying St. Peter aquifer and (2) has greater capacity than currently used for public-water supply (Mills and others, 2002). Throughout most of north-central and northwestern Illinois, the overlying Glenwood unit confines the St. Peter aquifer, a regionally important source of ground water. Because few deep wells open to the St. Peter aquifer are present in the valley to provide necessary lithologic and stratigraphic information, presence of the confining unit throughout the valley is uncertain; deposits of sand and gravel up to 260-ft thick may directly overlie the St. Peter aquifer in large areas of the valley. Additionally, limited water-chemistry data are available to describe present (2000) quality of ground water in and near the valley. Such baseline information is necessary for tracking trends in this developing area between Rockford and Belvidere, where changes in land use and increased water withdrawal are expected.

The objectives of the component of the Belvidere ground-water study performed during 2000-01 were to (1) further delineate the hydrostratigraphy of the Troy Bedrock Valley by determining areas where the Glenwood confining unit may be absent, (2) assess present ground-water quality in the aquifers in and near the valley, and (3) provide additional analysis of ground-water-flow patterns in the vicinity of Belvidere to assist ground-water-protection and -remediation efforts. To accomplish these objectives, geologic information from available well-construction logs was reexamined, water-chemistry data were collected in and near the Troy Bedrock Valley, and particle-tracking analysis was done using the available flow model (Mills and others, 2002). By particle-tracking analysis, discharge locations for ground-water flow were determined and areas contributing recharge to the Belvidere municipal wells and selected private wells were delineated.

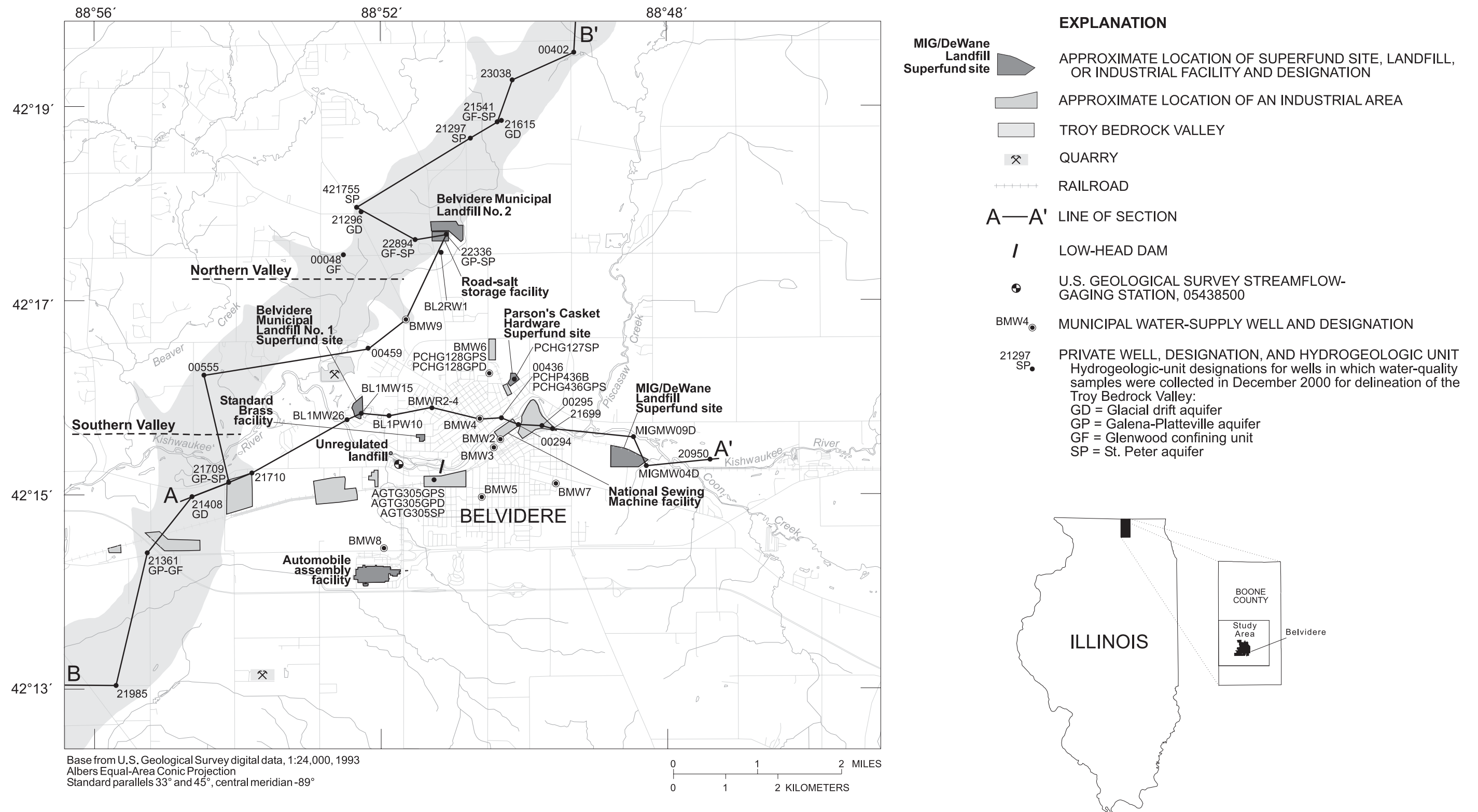


Figure 1. Study area, hazardous-waste and industrial sites, municipal water-supply wells, selected private wells, and lines of section A-A' and B-B' in the vicinity of Belvidere, Ill.

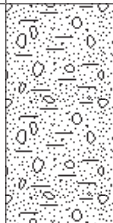
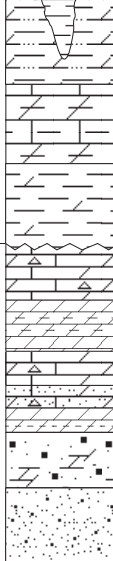
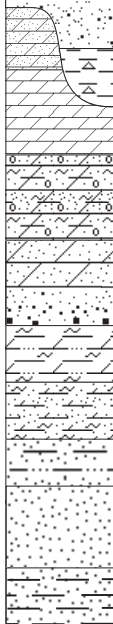
SYSTEM	ROCK-STRATIGRAPHIC UNIT	HYDRO-GEOLOGIC UNIT		LOG	THICK-NESS (FEET)	DESCRIPTION	
QUATERNARY	Undesignated	Glacial drift aquifer and confining unit			0-385	Unconsolidated glacial deposits-pebbly clay (till), silt, sand and gravel Alluvial silts and sands of Holocene age along streams	
					Fissure fillings	Shale, sandy, brown to black	
ORDOVICIAN	Maquoketa Shale Group	confining unit			0-45	Shale, silty, dolomitic, greenish gray, weak (Upper unit) Dolomite and limestone, white, light gray, interbedded shale (Middle unit) Shale, dolomitic, brown, gray (Lower unit)	
	Galena Group	Galena-Platteville aquifer	Ordovician aquifer system		0-300	Dolomite and/or limestone, cherty (Lower unit) Dolomite, shale partings, speckled Dolomite and/or limestone, cherty, sandy at base	
	Platteville Group						
	Glenwood Formation	confining unit			0-55	Dolomite, sandstone; silty	
	St. Peter Sandstone	St. Peter aquifer			180-290	Sandstone, fine to coarse grained; locally cherty red shale at base	
	CAMBRIAN	Potosi Dolomite			confining unit		
Franconia Formation		60-100		Dolomite, sandstone and shale, glauconitic, green to red, micaceous			
Ironton Sandstone		Ironton-Galesville aquifer	115-160	Sandstone, fine to coarse grained, well sorted; upper part dolomitic			
Galesville Sandstone			115-380	Shale and siltstone, dolomitic, glauconitic; sandstone, dolomitic, glauconitic			
Eau Claire Formation		confining unit	about 1,600	Sandstone, coarse grained, white, red in lower half; lenses of shale and siltstone, red, micaceous in upper part			
Elmhurst Sandstone Member		Elmhurst-Mt. Simon aquifer	unknown	Shale and siltstone (?)			
Mt. Simon Sandstone					confining unit (?)		
PRECAM-BRIAN							

Figure 2. Classification of rock-stratigraphic and hydrogeologic units underlying the vicinity of Belvidere, Ill. (figure modified from Woller and Sanderson, 1974, fig. 1).

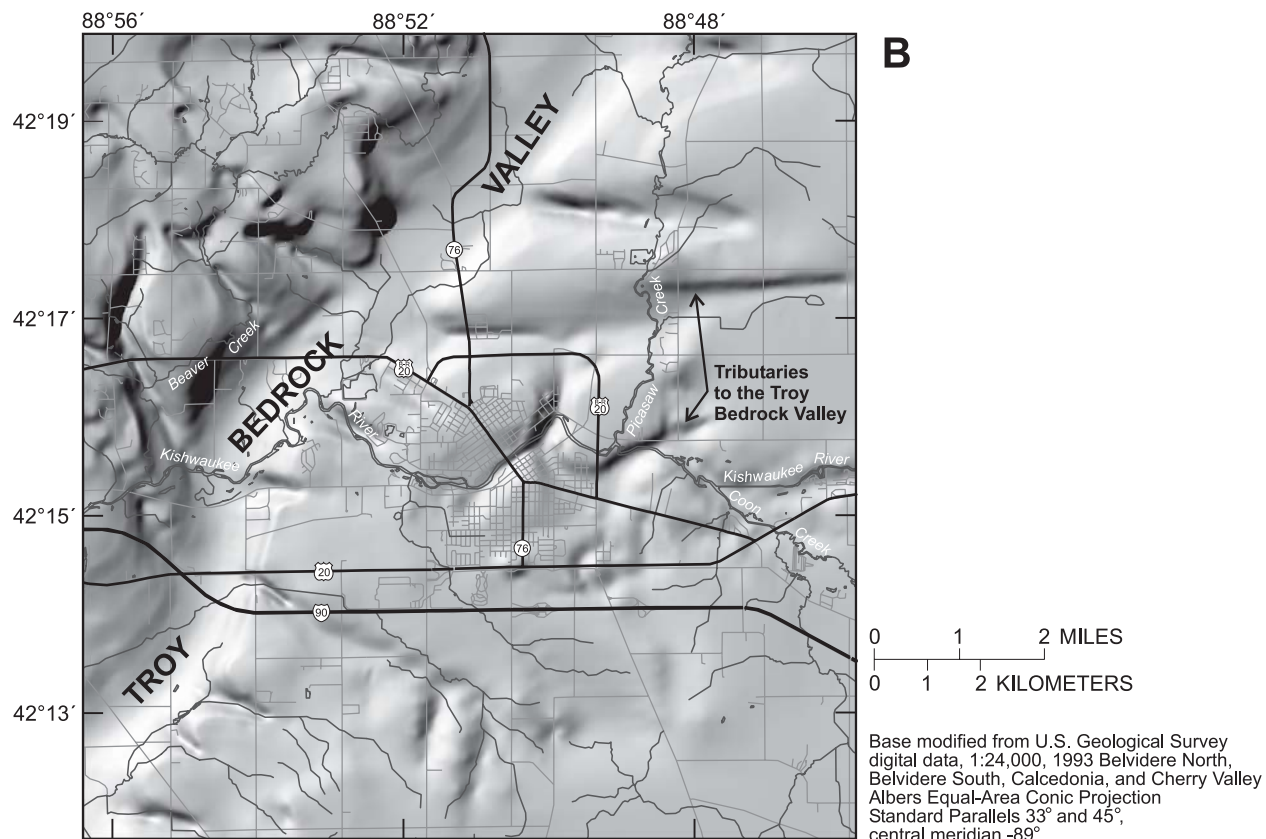
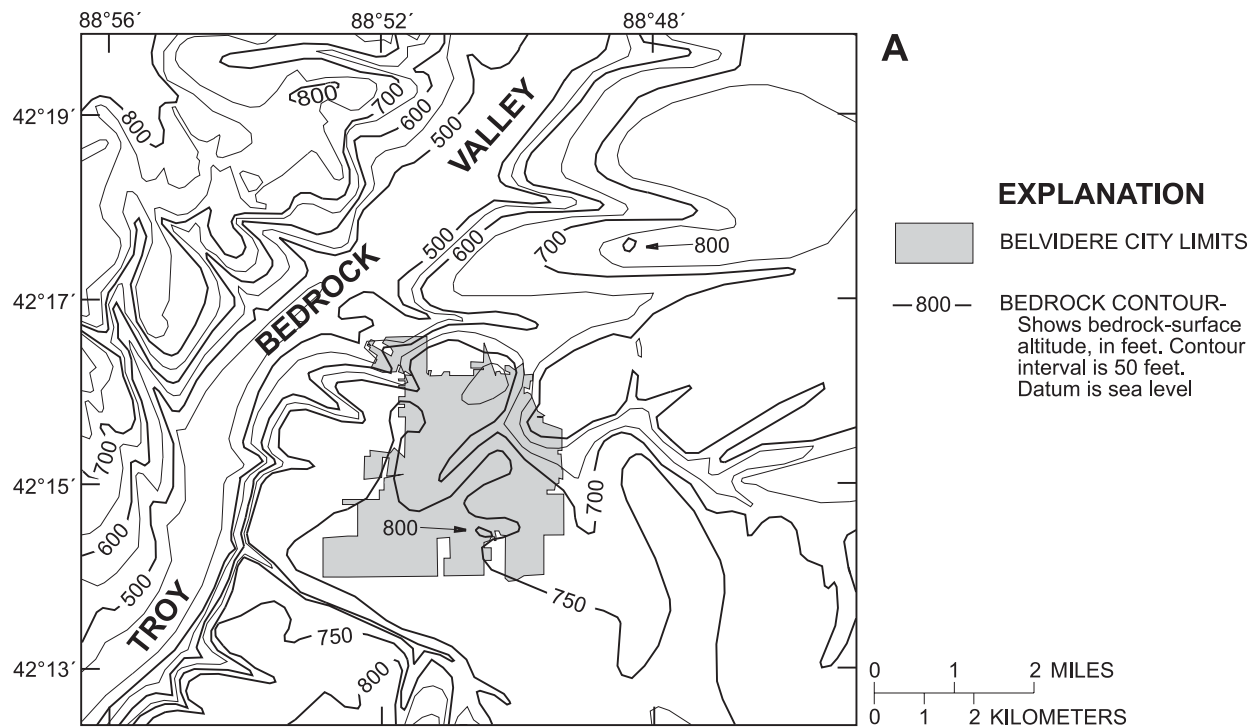


Figure 3. The Troy Bedrock Valley near Belvidere, Ill., as indicated by (A) bedrock topography and (B) shaded relief of the bedrock surface (figure A modified from Berg and others, 1984, fig. 10).

Purpose and Scope

This report presents and interprets water-chemistry data collected primarily during December 2000, briefly describes the previously developed ground-water-flow model, and presents results of particle-tracking analysis. Water-chemistry data primarily include tritium, field-determined characteristics, major ions, and VOC's; selected trace element, radon, and radium data also are included. Interpretations of water-chemistry data are limited to those data associated with the study objectives of delineating the hydrostratigraphy and water quality of the Troy Bedrock Valley. These data are examined with respect to geologic information from available well-construction logs. Other VOC data collected for an ongoing assessment of water quality in the bedrock aquifers underlying Belvidere are presented, but not interpreted; the reader is referred to Mills and others (1999, 2002) for details of this assessment.

Particle-tracking analysis includes (1) spatial distribution of leakage across the top of the Galena-Platteville aquifer, (2) ground-water-flow paths from known and possible contaminant-source areas to discharge locations, and (3) areas contributing recharge to Belvidere municipal wells and private wells withdrawing greater than 1 Mgal/yr, based on withdrawal rates in 1993 and 2000. Limitations of the model, inherent assumptions of particle-tracking analysis, and information on regional ground-water flow and the possible relation to contaminant distribution are discussed.

Study Area

The study area comprises about 80 mi² in southern Boone County and includes the city of Belvidere ([fig. 1](#)). The Troy Bedrock Valley transects the western part of the study area, trending southwestward into Winnebago County and northeastward into Wisconsin ([fig. 3](#)). The glacial drift aquifer, Galena-Platteville aquifer, and sandstone aquifers of the Cambrian-Ordovician aquifer system (including the uppermost St. Peter aquifer) compose the transmissive units of the ground-water-flow system ([fig. 2](#)). The glacial drift aquifer, thickest within the Troy Bedrock Valley ([figs. 3, 4, 5](#)), thins to lenses of sand and gravel within thicker till deposits beyond the

valley and north of the Kishwaukee River. East of the valley and south of the Kishwaukee River, the aquifer generally is not present. One municipal well (BMW9; [fig. 1](#)) is open to the glacial drift aquifer.

The approximately 300-ft thick Galena-Platteville aquifer consists of fractured dolomite that yields up to 40 gal/min to private water-supply wells in the area (Berg and others, 1984). Six municipal wells (BMW2-BMW7) are open, in part, to this aquifer and, in part, to the deeper bedrock aquifers. Five or fewer hydraulically active bedding-plane partings and an undetermined number of inclined fractures may be the principal locations of ground-water flow within the Galena-Platteville aquifer and migration routes of VOC's into area water-supply wells (Mills and others, 2002). The sandstone aquifers of the Cambrian-Ordovician aquifer system are the principal source of water to the municipal wells open to bedrock aquifers. One well (BMW8) is open exclusively to the sandstone aquifers. Principal confining units include deposits of clay and silt that locally overlie and (or) are interbedded within the glacial drift aquifer, the approximately 35-ft thick Glenwood confining unit, and at least two 40-300-ft thick units of dolomite, shale, or siltstone that separate the sandstone aquifers of the Cambrian-Ordovician aquifer system ([fig. 2](#)). The hydrogeologic framework of the ground-water-flow system in the vicinity of Belvidere is described further in the section "Model Description and Limitations" and in detail in Mills and others (2002).

Acknowledgments

Various persons are acknowledged for their contribution to the study. Jim Grimes, Superintendent of the Belvidere Water and Sewer Department, and Craig Lawler, Director of the Belvidere Public Works Department, provided withdrawal data for the municipal wells and authorized their use for ground-water sampling. The citizens of Belvidere generously granted access to their wells for sampling. Jason Thorpe and Amy Hacker of the IEPA assisted in sampling and technical review of the particle-tracking analysis, respectively.

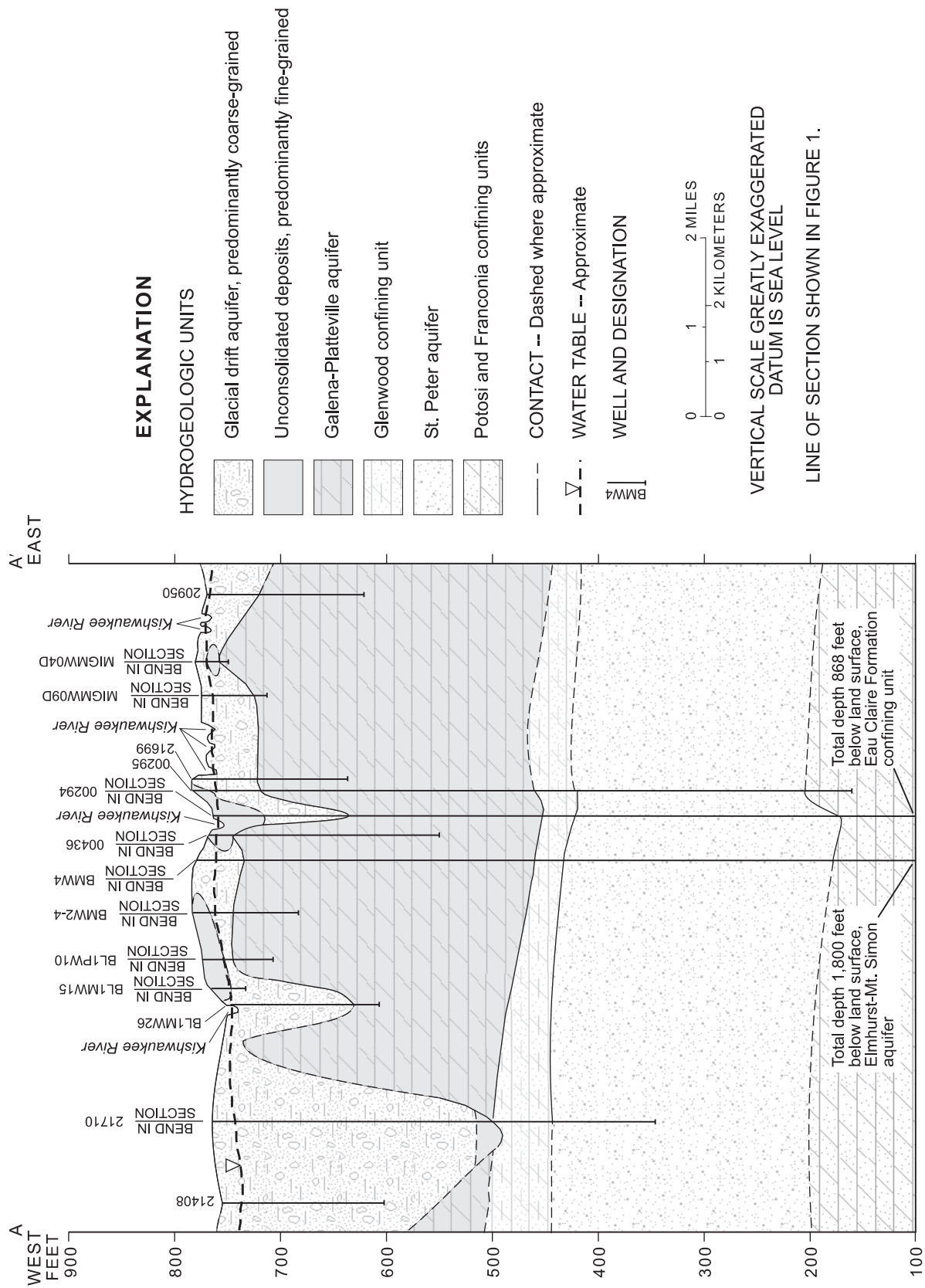


Figure 4. Hydrogeologic section A-A' through the vicinity of Belvidere, Ill.

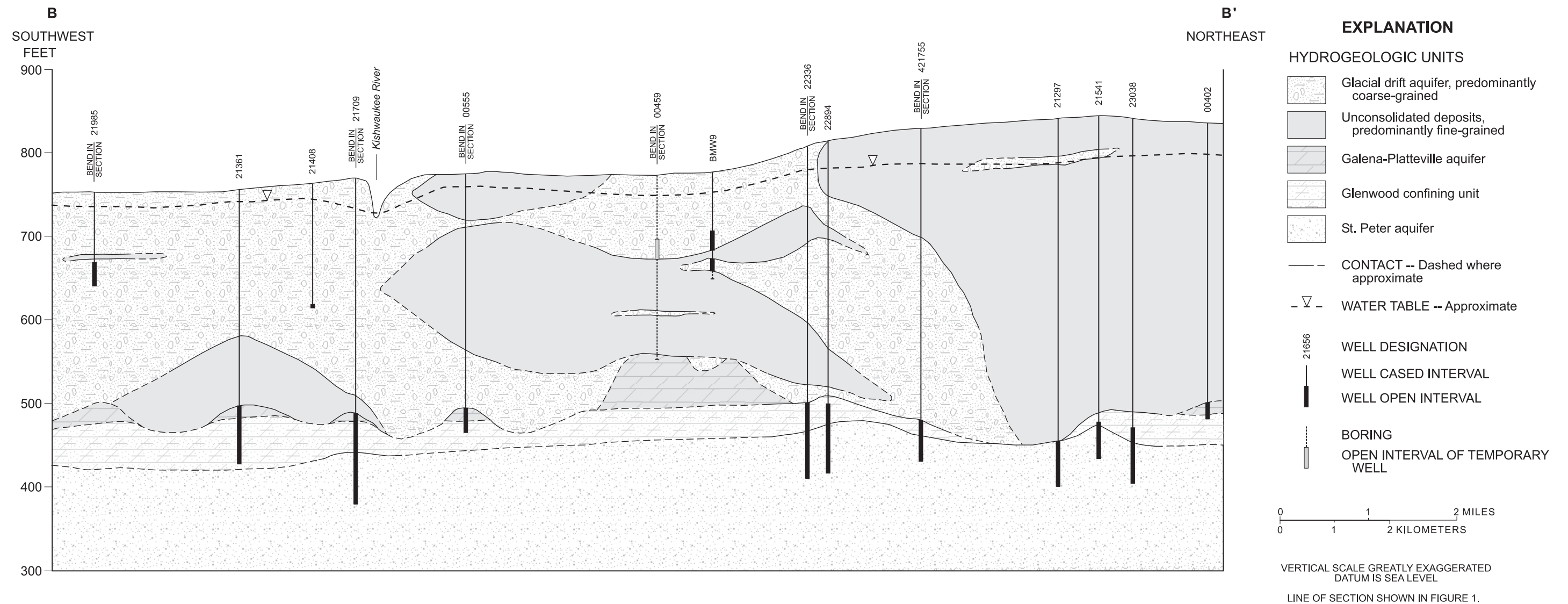


Figure 5. Hydrogeologic section B-B' through the vicinity of Belvidere, Ill.

STUDY METHODS

The following sections of this report describe the methods used to collect, analyze, and interpret ground-water-chemistry data. Also described are the computer codes and methods used to simulate ground-water flow and analyze flow patterns and travel times by particle tracking.

Ground-Water Sampling and Analysis

As a possible alternative to drilling, water-chemistry data were obtained and evaluated to determine if the Glenwood confining unit is absent within parts of the Troy Bedrock Valley. These data also provided information on present (2000) water quality in aquifers in and near the valley. Samples were collected for analysis of tritium, field-determined characteristics, major ions, and VOC's from three private water-supply wells (21296, 21408, 21615) open to the glacial drift aquifer that composes the valley and five private water-supply wells (21361, 21541, 21709, 22336, 421755) open to the bedrock aquifers (Galena-Platteville, St. Peter) that underlie the valley. These analytical data were supplemented with available data from a Belvidere municipal well (BMW9) open to the glacial drift aquifer and compared with available data from two monitoring wells (AGTG305GPS, PCHG127SP) open to the St. Peter aquifer outside (about 1.5 mi southeast) of the valley ([fig. 1](#)).

Additional samples were collected for analysis of the present water quality in aquifers in and near the valley. One sample was collected for analysis of trace elements from a well open to the glacial drift aquifer (21408) in the southern part of the valley and another for analysis of radon-222, radium-226, and radium-228 from a well (421755) open to the St. Peter aquifer in the northern part of the aquifer ([fig. 1](#)). Radium-226 results are not presented because of laboratory-analytical problems.

Tritium is a radioisotope of hydrogen that can be used to estimate relative age of ground water and extent of confinement and vulnerability of aquifers to contamination. Beginning in 1954, with the onset of above-ground nuclear-weapons testing, naturally occurring levels of atmospheric tritium were increased from about 5 tritium units (TU's; equivalent to 16 pCi/L) to over 1,000 TU's. Cessation of nuclear testing and radioactive decay have reduced atmospheric levels to current levels of about 50-100 TU's in North America (University of Ottawa, 2000). Tracking the

pulse of tritium-enriched water recharging aquifers allows the time since initiation of recharge to be estimated. Presently (2000), ground water with levels at or less than 1 TU represents recharge that originated before about 1954. The USEPA and IEPA consider aquifers with tritium levels at or less than 1 TU as confined, thus, not vulnerable to contamination and aquifers with tritium levels at or greater than natural levels of 5 TU's as unconfined, thus, vulnerable to contamination (Illinois Environmental Protection Agency, 1999).

Differences in tritium levels (and, thus, ages of ground water) and possibly other aspects of water chemistry (field-determined characteristics, constituent concentrations, water type) in aquifers assumed to be vertically adjacent may indicate the presence of an intervening confining unit that limits hydraulic connection between the aquifers. Similarities in tritium levels and water chemistry in the aquifers may indicate hydraulic connection between the aquifers, and, thus, the absence of a confining unit (or possibly a weakly confining unit that is thin and (or) permeable).

For this study, samples that have tritium levels greater than 1 TU (age is less than about 46 years) are assumed to be from wells open to the unconfined glacial drift or Galena-Platteville aquifers that overlie the Glenwood confining unit or in or near parts of the St. Peter aquifer where the Glenwood confining unit may be absent, such as within the deepest parts of the Troy Bedrock Valley. Possibly, where unused, under-used, or inadequately grouted wells or fractures penetrate the Glenwood confining unit, tritium levels within the St. Peter aquifer locally may be greater than 1 TU. Water in deep (greater than about 150 ft?), confined parts of the glacial drift aquifer and aquifers that underlie an extensive area of the Glenwood confining unit are assumed to have tritium levels less than 1 TU. This conceptualization is based, in part, on tritium and VOC data previously collected from the various aquifers of the area at locations outside of the valley (Mills and others, 2002). The conceptualization, with respect to the age of ground water, is illustrated in [figure 6](#).

As part of an ongoing assessment of VOC's in the bedrock aquifers that underlie Belvidere, samples also were collected from a network of 14 wells during December 2000. The sampled wells included municipal wells BMW2-BMW7 and BMW9, and monitoring wells AGTG305GPS, AGTG305GPD, AGTG305GPD, PCHG128GPS, PCHG128GPD, PCHP436B, and PCHG436GPS ([fig. 1](#)).

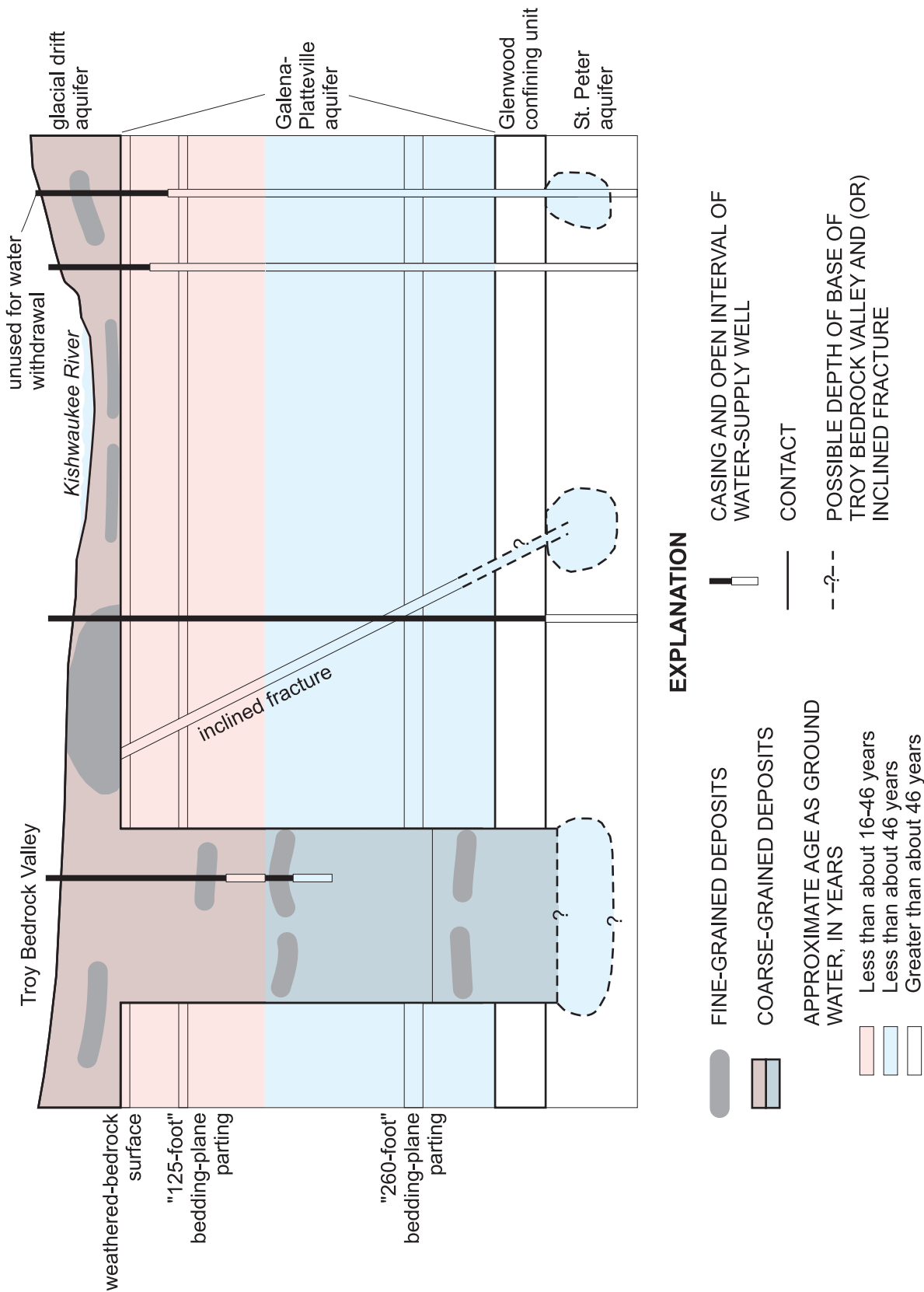


Figure 6. Relative age of water in aquifers in the vicinity of the Troy Bedrock Valley near Belvidere, Ill.

Locations and descriptions of the 22 wells from which samples were collected and the types of water-chemistry analyses are listed in [table 1](#). Samples were collected using methods described in Mills and others (1998, 1999, 2002). The methods include collection and analysis of quality-assurance samples; information on these samples can be obtained from the USGS, Illinois District office, on request.

Major-ion, trace-element, and radon samples were analyzed by the USGS National Water-Quality Laboratory in Lakewood, Colo. Tritium samples were analyzed by a USGS laboratory in Menlo Park, Calif. The radium sample was analyzed by a USGS contract laboratory in Richland, Wa. VOC samples were analyzed by a laboratory managed under the USEPA Contract Laboratory Program.

Model Description and Limitations

The USGS modular computer code MODFLOW (McDonald and Harbaugh, 1988) was used to simulate steady-state, ground-water flow of the 80-mi² study area (Mills and others, 2002). The purpose of the model was, in part, to determine sources and sinks of regional ground-water flow. The principal source of ground water is precipitation within the study area. Principal sinks include the Kishwaukee River, its tributaries, and water-supply wells in the area. Of the wells, the primary sink is the system of eight Belvidere municipal wells.

The flow model consists of four layers that represent the glacial drift aquifer (layer 1), the Galena-Platteville aquifer (layer 2), the Glenwood confining unit (layer 3), and the sandstone aquifers of the Cambrian-Ordovician aquifer system (layer 4) (shown generally in [fig. 4](#)). Four zones delineated within the glacial drift aquifer represent hydrologically different parts of the aquifer system. These zones include (1) the southern half of the Troy Bedrock Valley and Kishwaukee River valley, where sand-and-gravel deposits predominate and generally are greater than 50 ft thick, (2) the flood plains of the Kishwaukee River and its principal tributaries, where sand-and-gravel deposits predominate and generally are less than 50 ft thick, (3) the northern part of the study area, including the northern half of the Troy Bedrock Valley, where sand-and-gravel deposits may be present within thicker sequences of glacial till, and (4) the southern part of the study area, where till deposits predominate. Lateral boundaries to ground-water flow in the glacial drift and

deeper aquifers were placed at distances where water levels were expected to be unaffected by ground-water withdrawals from high-capacity wells in the vicinity of Belvidere; water levels in the glacial drift aquifer were specified on the basis of estimates from nearby measurements and mapped levels in streams and lakes. The eastern boundary of the Cambrian-Ordovician aquifer system (layer 4) was located along a ground-water divide (Visocky, 1993, 1997); water levels along the western boundary were specified to account for substantial withdrawals in nearby Rockford (Avery, 1999; Kirk, 1987).

The model was calibrated to ground-water levels measured in spatially distributed and vertically nested wells in July 1993. Ground-water discharge, as estimated from streamflows measured in the Kishwaukee River and its principal tributaries in September 2000, also was used in the model calibration.

Ground-water-withdrawal rates for the period of calibration (1993) were included for all wells reported to produce more than 1 Mgal/yr ([table 2](#)). These wells included the seven Belvidere municipal wells in use (BMW3-BMW9), three private wells (00294, 00295, BL2RW1), and one or more wells used to de-water a rock quarry in the southwestern part of the study area ([fig. 1](#)). Withdrawals by the municipal wells typically range from about 0.3 to 0.8 Mgal/d per well (J.A. Grimes, Belvidere Water and Sewer Department, written commun., 1999, 2001); during the model-calibration period, well BMW2 was not in use and well BMW3 was used infrequently. Withdrawals by the private wells typically range from about 0.01 to 0.2 Mgal/d. About 80 percent of the wells are located within the city of Belvidere ([fig. 1](#)).

A fundamental assumption of MODFLOW is that the hydrogeologic units represented by model layers are composed of continuous porous media. Although porosity that affects flow in the Galena-Platteville aquifer is represented predominantly by fractures and bedding-plane partings, these openings are interconnected and flow does occur through vuggy intervals within the carbonate matrix. As such, at the regional scale of flow simulation, the assumption of a continuous porous media is considered reasonable. Evaluation of possible model error associated with using hydrologic data from different years for calibration indicated that the model results were not affected substantially (Mills and others, 2002).

Table 1. Description of wells and types of water-quality data collected in the vicinity of Belvidere, Ill., December 2000

Hydrogeologic unit to which well is open: GD, glacial drift aquifer; GP, Galena-Platteville aquifer; GF, Glenwood Formation confining unit; SP, St. Peter aquifer; OR, Ordovician aquifer system (Galena-Platteville and St. Peter aquifers); CO, Cambrian-Ordovician aquifer system (Galena-Platteville, St. Peter, Ironton-Galesville, and (or) Elmhurst-Mt. Simon aquifers)

Open or screened interval of well: in feet below land surface

Type of well: P, private water supply; T, temporary boring; B, Belvidere municipal water supply; M, monitoring

Purpose of sampling: --, not sampled, used for hydrogeologic mapping; TD, delineation of hydrostratigraphy of Troy Bedrock Valley; TQ, ground-water quality in Troy Bedrock Valley; BQ, ground-water quality in Belvidere

Sampled for major ions: --, not sampled, used for hydrogeologic mapping; Y, yes; N, no

Sampled for trace elements: --, not sampled, used for hydrogeologic mapping; Y, yes; N, no

Sampled for tritium: --, not sampled, used for hydrogeologic mapping; Y, yes; N, no

Sampled for radon and radium: --, not sampled, used for hydrogeologic mapping; Y, yes; N, no

Well designation	Latitude	Longitude	Hydrogeologic unit	Open or screened interval of well	Type of well	Purpose of sampling	Sampled for major ions	Sampled for trace elements	Sampled for volatile organic compounds	Sampled for tritium	Sampled for radon and radium
00048	421729	885223	GF	312-338	P	--	--	--	--	--	--
00294	421543	885004	CO	239-868	P	--	--	--	--	--	--
00295	421543	884944	CO	62.8-627	P	--	--	--	--	--	--
00402	421926	884917	GP-GF ¹	335-354	P	--	--	--	--	--	--
00436	421548	885018	GP	25-215	P	--	--	--	--	--	--
00459	421630	885910	GP	220	T	--	--	--	--	--	--
00555	421614	885429	GP-GF ¹	280-306	P	--	--	--	--	--	--
20950	421522	884723	GP	57-150	P	--	--	--	--	--	--
21296	421754	885215	GD	60-100	P	TD	Y	N	Y	Y	N
21297	421839	885045	SP	385-440	P	--	--	--	--	--	--
21361	421423	881514	GP-GF ¹	260-330	P	TD	Y	N	Y	Y	N
21408	421459	885450	GD	148-150	P	TD, TQ	Y	Y	Y	Y	N
21541	421854	885016	GF-SP ³	366-410	P	TD	Y	N	Y	Y	N
21615	421852	885010	GD	360-362	P	TD	Y	N	Y	Y	N
21699	421541	884935	GP	61-145	P	--	--	--	--	--	--
21709	421509	885407	GP-SP ³	279-390	P	TD	Y	N	Y	Y	N
21710	421514	885348	OR	266-420	P	--	--	--	--	--	--
21985	421301	885546	GD	85-110	P	--	--	--	--	--	--

Table 1. Description of wells and types of water-quality data collected in the vicinity of Belvidere, Ill., December 2000–Continued

Well designation	Latitude	Longitude	Hydrogeologic unit	Open or screened interval of well	Type of well	Purpose of sampling	Sampled for major ions	Sampled for trace elements	Sampled for volatile organic compounds	Sampled for tritium	Sampled for radon and radium
22336	421742	885106	GF-SP ³	312-400	P	TD	Y	N	Y	Y	N
22894	421742	885123	GF-SP ³	313-405	P	--	--	--	--	--	--
23038	421912	885013	GF-SP ³	370-440	P	--	--	--	--	--	--
421755	421759	885221	GF-SP ³	352-398	P	TD,TQ	Y	N	Y	Y	Y
AGTG305GPS	421508	885116	GP	110.0-115.0	M	BQ	N	N	Y	N	N
AGTG305GPD	421508	885116	GP	246.4-251.4	M	BQ	N	N	Y	N	N
AGTG305SP	421508	885116	SP	352.8-357.8	M	BQ	Y	N	Y	4Y	N
BL1MW15	421550	885216	GD	20.6-37.1	M	--	--	--	--	--	--
BL1MW26	421547	885228	GP	137-142.5	M	--	--	--	--	--	--
BL1PW10	421549	885153	GP	56-66	P	--	--	--	--	--	--
BL2RW1	421731	885107	OR	287.5-520	P	--	--	--	--	--	--
BMW2	421534	885019	CO	50-1,860	B	BQ	N	N	Y	N	N
BMW3	421530	885025	CO	55-1,800	B	BQ	N	N	Y	N	N
BMW4	421547	885036	CO	152-1,800	B	BQ	N	N	Y	N	N
BMW5	421458	885034	OR	151.8-610	B	BQ	N	N	Y	N	N
BMW6	421615	885028	CO	110-868	B	BQ	N	N	Y	N	N
BMW7	421506	884933	CO	192-969	B	BQ	N	N	Y	N	N
BMW8	421427	885158	CO	362-875; 995-1,390	B	TD	5Y	N	N	4Y	N
BMW9	421649	885139	GD	70-90; 115-120	B	BQ,TD	N	N	Y	4Y	N
BMW2-4	421554	885117	GP	40-96.5	P	--	--	--	--	--	--
PCHG127SP	421608	885013	SP	370.7-375.7	M	TD	5Y	N	N	4Y	N
PCHG128GPS	421615	885027	GP	116.0-121.0	M	BQ	N	N	Y	N	N
PCHG128GPD	421615	885027	GP	253.5-258.5	M	BQ	N	N	Y	N	N
PCHP436B	421548	885018	GP	30.0-35.0	M	BQ	N	N	Y	N	N
PCHG436GPS	421548	885018	GP	102.3-107.3	M	BQ	N	N	Y	N	N

¹ Water is withdrawn primarily from the Galena-Platteville aquifer.

² Total depth of temporary boring.

³ Water is withdrawn primarily from the St. Peter aquifer.

⁴ Sample collected during March 1999 (Mills and others, 2002).

⁵ Sample collected during 1995 (Mills and others, 1998).

Table 2. Withdrawal rates of municipal wells and private wells withdrawing greater than 1,000,000 gallons per year in the vicinity of Belvidere, Ill.

[Mgal/d, million gallons per day; --, not applicable]

Hydrogeologic unit¹: GD, glacial drift aquifer; GP, Galena-Platteville aquifer; OR, Ordovician aquifer system; CO, Cambrian-Ordovician aquifer system

Well designation	Hydrogeologic unit	Annual withdrawals ²	
		³ 1992-93 (Mgal/d)	⁴ 2000 (Mgal/d)
BMW2	CO	0.000	0.31
BMW3	CO	.004	.45
BMW4	CO	.32	.25
BMW5	OR	.32	.28
BMW6	CO	.43	.33
BMW7	CO	.55	.35
BMW8	CO	.57	.97
BMW9	GD	.57	.47
⁵ 00294	CO	.17	.17
⁵ 00295	CO	.016	.016
⁵ BL2RW1	CO	.012	.012
⁶ Quarry	GP	.022	.022
TOTAL	--	2.98	3.63

¹ Hydrogeologic units described in figure 2.

² Withdrawal data for municipal wells BMW2-BMW9 were provided by the city of Belvidere (J.A. Grimes, Belvidere Water and Sewer Department, written commun., 1999, 2002).

³ August 1992–July 1993; annual period used for model calibration (Mills and others, 2002)

⁴ January–December 2000. Withdrawal data are not available for well BMW8 for November and December; data are estimated from withdrawal history.

⁵ Withdrawal data are from the Illinois Water Inventory Program (K.J. Hlinka, Illinois State Water Survey, written commun., 1995). Data for wells 00294 and BL2RW1 are from 1994; data for well 00295 are from 1986.

⁶ Withdrawal data are estimated from information provided by quarry personnel (D.H. Fischer, Rockford Sand and Gravel, Inc., oral commun., 1995).

Sensitivity analysis indicated that accurate estimates of the recharge rate and horizontal hydraulic conductivity of the deposits composing the sand-dominated valley edge of the glacial drift aquifer and the sandstone aquifers of the Cambrian-Ordovician aquifer system are the most critical information needed for accurate characterization of the flow system.

Ground-water-flow paths simulated in a flow model can be delineated and shown using particle tracking. By use of the USGS particle-tracking code MODPATH (Pollock, 1989), particle pathlines were computed in each cell of the regional flow model of Belvidere. MODPATH uses output from simulations obtained with the computer code MODFLOW (McDonald and Harbaugh, 1988). Using the calibrated hydraulic conductivity and the computed three-dimensional hydraulic gradients, hypothetical water particles are tracked along the hydraulic gradient within the computed flow field. Particles may be tracked forward from recharge to discharge locations or backward from discharge to recharge locations.

MODPATH uses a semi-analytical particle-tracking scheme based on the assumption that the ground-water velocity components within a model cell vary linearly. The velocity components are based on the intercell flow volumes computed with MODFLOW. The average linear velocity component across each face in a model cell is obtained by dividing the flow volume at a cell face by the cross-sectional area of the cell and the effective porosity of the material within a cell. Simple linear interpolation is used to compute the principal velocity components within a cell.

The particle-tracking scheme used by MODPATH is valid only for computing and interpolating advective velocities from intercellular flows, such as those computed with MODFLOW. Accordingly, the particle pathlines are based on advective particle movement and travel times—no diffusion, dispersion, or chemical or microbiological retardation is incorporated into the movement of the particles. The analyses presented in this report are based on a model in which steady-state conditions are assumed. Although changes in withdrawal rates or other stresses in the system over time likely will affect the particle pathlines and travel times, contributing areas to wells tend to reflect long-term (years), average flow patterns and, generally, are insensitive to shorter-term cyclic variations in natural (such as seasonal) and man-made (such as well withdrawals) stresses.

In conventional analyses, delineations of areas that contribute recharge to wells are projected from the top of the water table to land surface (fig. 7). Such an approach aids mapping the contributing area and developing ground-water-protection measures on the overlying land surface. Accuracy of the projections decreases as the distance between land surface and the water table increases. For confined aquifers, where the recharge from land surface may originate outside the simulated study area, such projections are inappropriate. Such projections also may be inappropriate where leakage through overlying confining beds represents a minor percentage of total flow to a confined aquifer. The projected areas provide no information about the proportion of flow through the confining unit.

Use and uncertainties of particle-tracking analysis to delineate ground-water-flow patterns and to estimate areas that contribute recharge to wells and ground-water travel times are discussed in detail and illustrated by Franke and others (1999). A detailed discussion of the limitations of the ground-water-flow model of Belvidere is included in Mills and others (2002). General uncertainties associated with MODFLOW and MODPATH, as well as uncertainties specific to the simulation of ground-water flow in the aquifers underlying Belvidere, are discussed below.

The numerical flow model contributes more uncertainty to the delineation of flow patterns and contributing areas and estimation of travel times than does the particle-tracking methodology. The calibrated model is a numerical representation of the flow system; simulated water levels do not precisely match measured water levels, and actual ground-water-flow paths are likely to be more complex than the simulated flow paths. Numerical approximations, scale limitations, grid design, boundary conditions, and calibration data each can affect the accuracy of the model and, therefore, the particle-tracking analysis. Heterogeneity of the hydraulic properties of the aquifers underlying the study area, particularly hydraulic conductivity, is considered to have the greatest effect on the accuracy on this and other simulations of ground-water flow. Scale limitations of the numerical model also are considered to notably affect the accuracy of the simulation. Estimates of hydraulic conductivity can vary over as much as five orders of magnitude in the fractured dolomite of the Galena-Platteville aquifer and three orders of magnitude in the sand-and-gravel deposits of the glacial drift aquifer.

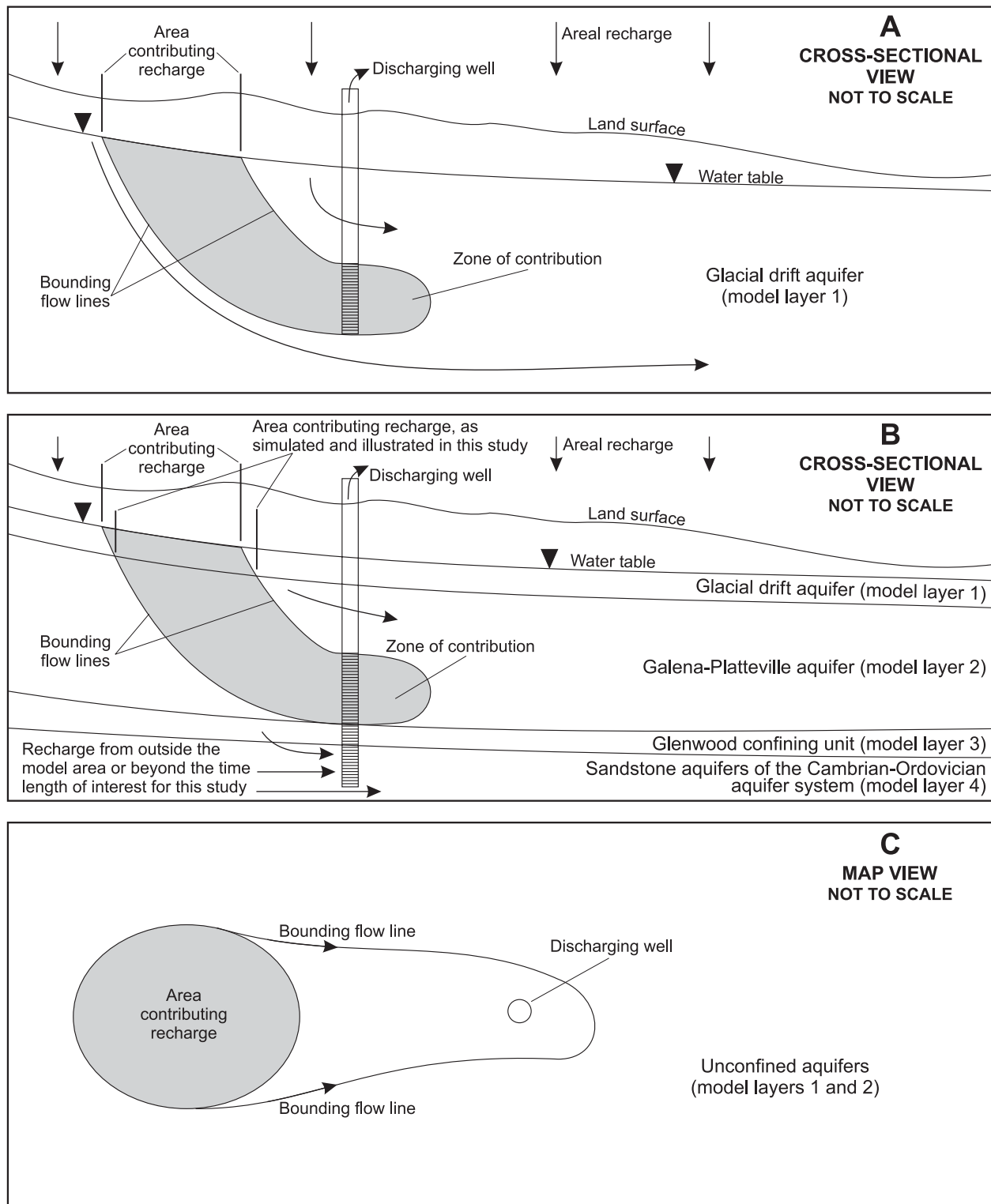


Figure 7. Area contributing recharge to a single discharging well in a simplified model of the ground-water-flow system in the vicinity of Belvidere, Ill., (A) cross-sectional view of a well open to the unconfined glacial drift aquifer, (B) cross-sectional view of a well open to the unconfined Galena-Platteville aquifer and underlying confined aquifers, and (C) map view of area contributing recharge to the unconfined aquifers (modified from Sheets, 1994, fig. 4).

The previously developed model was designed to investigate regional ground-water flow. Local flow, such as flow to small streams and flow adjacent to sources and sinks, may be represented insufficiently in the regional model. Additionally, the model does not account accurately for the local effects of secondary porosity in the Galena-Platteville aquifer. Bedding-plane partings and inclined fractures are known to provide preferential pathways for water movement and suspected to provide pathways for contaminant movement (Mills and others, 2002).

In delineation of areas contributing recharge to wells, errors in estimation of hydraulic conductivity result in substantial uncertainty in the representation of hydraulic gradients upgradient of the wells (Varljen and Shafer, 1991), and, thus, in estimation of ground-water travel times. Travel times also are affected by uncertainties associated with estimation of bulk porosity of the glacial and fractured-bedrock aquifers. Porosities were estimated on the basis of literature values (Freeze and Cherry, 1979), laboratory measurements (Mills and others, 1998, table 4), and geophysical methods (Mills and others, 1998, appendix 6). With possible error in estimation of porosity of up to one order of magnitude, travel times in the Galena-Platteville and glacial drift aquifers may be similarly over- or under-estimated.

The effects of hydraulic-property heterogeneity and scale limitations on the accuracy of the Belvidere flow model, however, are mitigated to a large extent in that most of the hydraulic-conductivity and porosity data were collected in the same part of the study area (within the city of Belvidere) where water-level data were concentrated for model calibration, model-cell sizes were smallest, and particle-tracking analysis was focused. Although the uncertainties and limitations associated with this and other numerical models should not be ignored, such models provide invaluable new and insight and understanding of ground-water-flow systems.

Uncertainties in the simulations can be reduced by more detailed field studies, including additional aquifer tests and water-level measurements. Results of the simulations can be further evaluated and refined with the availability of additional water-quality data.

DELINEATION OF TROY BEDROCK VALLEY

Delineation of the Troy Bedrock Valley, as discussed in this report, concerns additional determination of the geologic deposits (thus,

hydrogeologic units) that infill various parts of the valley (the unconsolidated deposits) and that underlie the valley (the bedrock deposits). Of particular concern is the presence or absence of the Glenwood confining unit beneath the deepest parts of the valley. Drilling and (or) geophysics could clearly resolve questions about the valley hydrostratigraphy. However, with depths of interest exceeding 300 ft and numerous locations in the valley requiring investigation, those exploratory methods were considered too expensive. Consequently, delineation relied on geologic (lithologic and stratigraphic information from construction logs) and water-quality data from the few water-supply wells previously installed in and near the valley. Evaluation of these data are presented in the following sections of this report.

Geologic Information

Presently (2001), only about 20 wells are distributed throughout the valley at depths (greater than about 300 ft) and locations necessary to delineate the hydrostratigraphy of the Troy Bedrock Valley ([figs. 1, 4, 5](#); [table 1](#)). At least 80 percent of these wells are located in the northern part of the valley. Dozens of wells open to 300 ft or greater have been installed in the valley since 1997. However, most of the wells are within or near a single housing development in the northern part of the valley and, thus, are not particularly useful in additional delineation of the valley hydrostratigraphy.

Geologic information from well-construction logs indicate that the valley typically is about 1 mi wide where primarily the underlying dolomite (composing the Galena-Platteville aquifer) is incised to depths greater than about 200 ft ([figs. 1, 4, 5](#)); at shallower depths, a 2- to 3-mi wide valley trace can be identified. In general, valley infill grades from predominately sand and gravel in the southern part of the valley to fine-grained (till) deposits in the northern part ([fig. 1](#)). Locally, particularly in the transitional region from the southern to the northern part of the valley and from mid-valley to valley edge, interlayered fine-grained and sand-and-gravel deposits are present. In most areas, the deep parts of the valley appear to be underlain by the argillaceous dolomite of the Glenwood confining unit. As indicated by well-construction logs, maximum uneroded thickness of this unit in the vicinity of the valley is about 55 ft; average uneroded thickness is about 35 ft. Where present, the minimum recorded thickness of the unit, possibly indicating erosion, is 12 ft.

Accurate determination of areas where the Glenwood confining unit may be absent in the valley is difficult from the available well-construction information. Only one well (21297, in the northern part of the valley) appears to be located within the deepest part of the valley ([figs. 1, 5](#)) and clearly indicates that unconsolidated (fine-grained) valley-fill deposits directly overlie the St. Peter aquifer ([figs. 1, 5](#)). With such limited information, various interpretations of the valley hydrostratigraphy are possible. Based on similar well information, the Illinois State Geological Survey (ISGS), in a county-scale study, interpreted and mapped most deep parts of the Troy Bedrock Valley with valley-fill deposits directly overlying the St. Peter aquifer (Berg and others, 1984) ([fig. 8a](#)).

An alternative interpretation of the valley hydrostratigraphy, as originally proposed by Mills and others (2002), suggests that the Glenwood confining unit has been fully eroded in only a small part of the northern part of the valley and possibly in the southernmost part of the valley, where the valley deepens ([fig. 8b](#)). In the northern part of the valley, the St. Peter aquifer, providing regional water supply, is overlain primarily by fine-grained deposits; thus, limited recharge (and possible contaminant movement) from shallow ground water to the regional aquifer is expected. In the southernmost part of the valley, thick sand-and-gravel deposits seem to directly overlie the St. Peter aquifer; thus, increased recharge (and possible contaminant movement) from shallow ground water to the regional aquifer, is expected.

With approximately the same well control available for mapping, differences between the ISGS and USGS delineations of the valley hydrostratigraphy seem attributable to differences in the mapping methods used by the ISGS and USGS. The ISGS method relies on the intersection of projected surfaces of stratigraphic units to determine the presence and position of the units in locations with inadequate well control. Apparently, the steep-sloping erosional surface of the Galena-Platteville aquifer, as indicated on the basis of remotely located wells, projects underneath the more flat-lying surface of the St. Peter aquifer. Thus, the Galena-Platteville aquifer and the Glenwood confining units are interpreted as absent in these parts of the valley. Also, the large areal scale of the ISGS study (as compared to the more local scale of this study) likely precluded detailed delineation of the valley hydrostratigraphy (Richard Berg, Illinois State

Geological Survey, oral commun., 2001). The USGS method assumes that the Glenwood confining unit is present unless its absence is indicated directly on the basis of a well-construction log (as in the northern part of the valley) or indirectly on the basis of the deepening trend of the valley (as in the southern part of the valley).

Water Chemistry

Analytical results of water samples collected from eight private water-supply wells during December 2000 for delineation of the hydrostratigraphy and water quality of the Troy Bedrock Valley are listed in [appendixes 1-5](#). Results are included for tritium, major ions, VOC's, and field-determined characteristics. Results of selective sampling also are included for trace elements, radon, and radium.

Tritium levels ranged from less than 0.1 TU to about 13.9 TU ([appendix 4, table 3, figs. 9, 10](#)). In general, tritium levels decrease with depth in the aquifers, but elevated levels (greater than 4 TU) are recorded at depths from 260 to 356 ft. Tritium levels in samples from only three wells (21541, 21615, 22336) were less than 1 TU; all of the wells are in the northern part of the valley ([fig. 1](#)). In the vicinity of these wells, each greater than 312 ft deep, either deposits of clay greater than about 280 ft thick or interlayered deposits of sand and clay, each greater than about 20 ft thick, overlie the Glenwood confining unit. One well (21615) is open to the glacial drift aquifer and two wells are open to the Glenwood confining unit and the St. Peter aquifer (21541, 22336).

Tritium levels were greater than 1 TU in samples from two wells open to the St. Peter aquifer (421755, 21709) ([fig. 1](#)). Although the Glenwood confining unit is present in the immediate vicinity of each well, the evidence for recent ground-water recharge (since 1954) indicates that nearby, the unit may be absent and the glacial drift and St. Peter aquifers are hydraulically connected. Well 421755 is located in the northern part of the valley and well 21709 in the southern part ([fig. 1](#)). Elevated values of DO (1.75 mg/L; less than 0.32 mg/L in other samples from glacial drift and bedrock aquifers near the valley) and Eh (184 mv; negative in other samples from bedrock aquifers near the valley), generally associated with unconfined aquifers, also were recorded for the sample from well 421755.

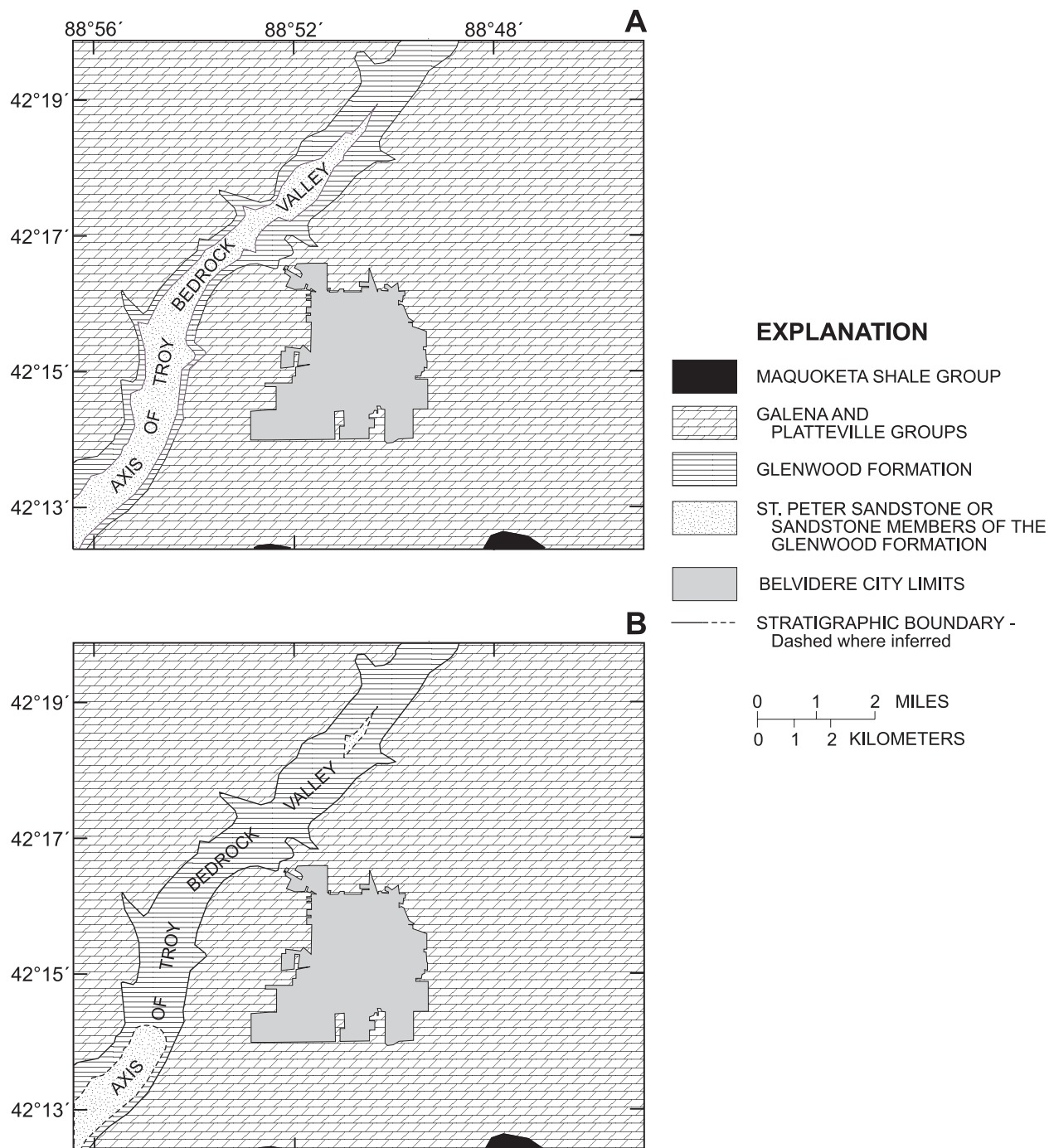


Figure 8. Possible stratigraphic geometries of the bedrock surface within the Troy Bedrock Valley near Belvidere, Ill., after (A) Berg and others (1984) and (B) Mills and others (2002).

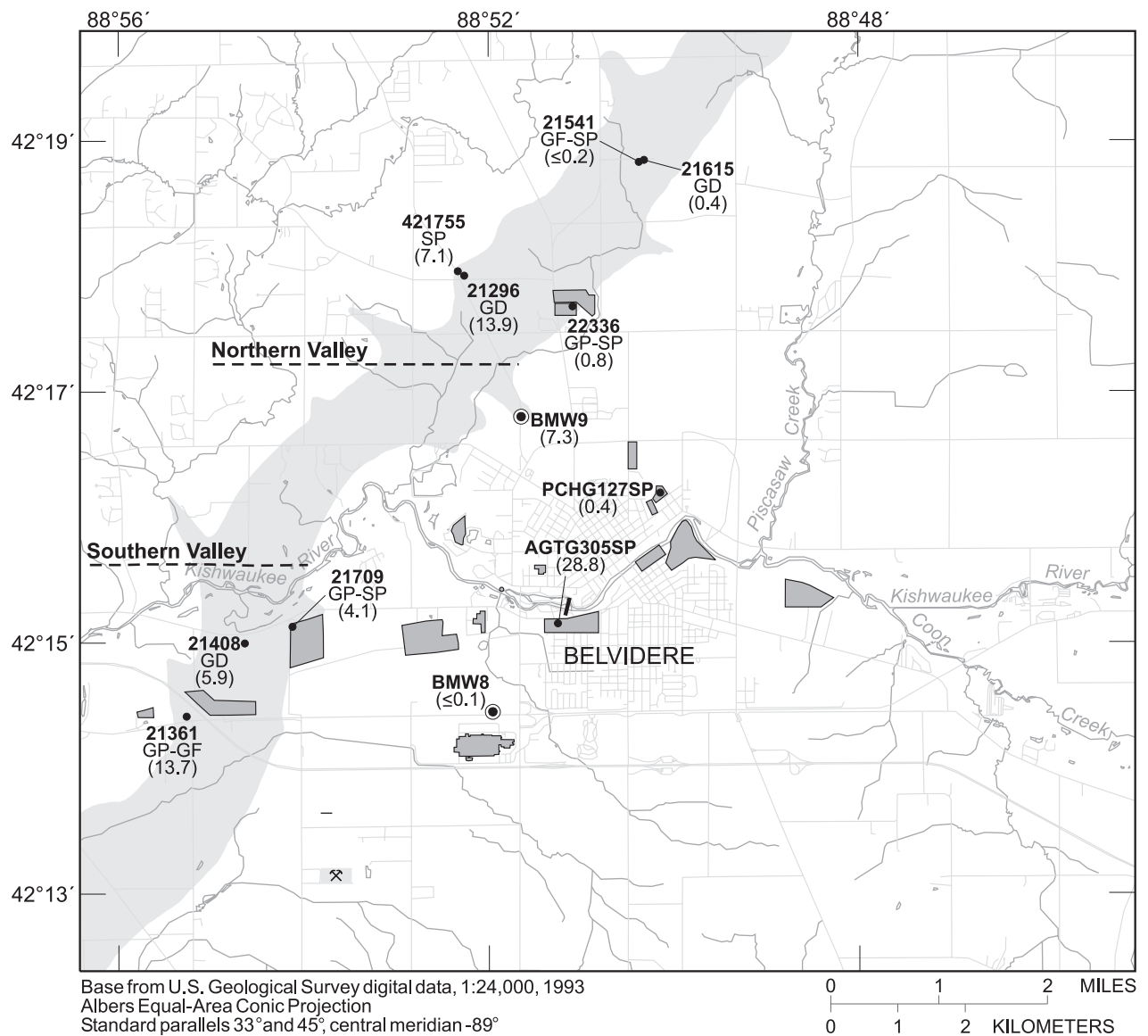


Figure 9. Tritium levels in aquifers in the vicinity of the Troy Bedrock Valley near Belvidere, Ill., 1999-2000.

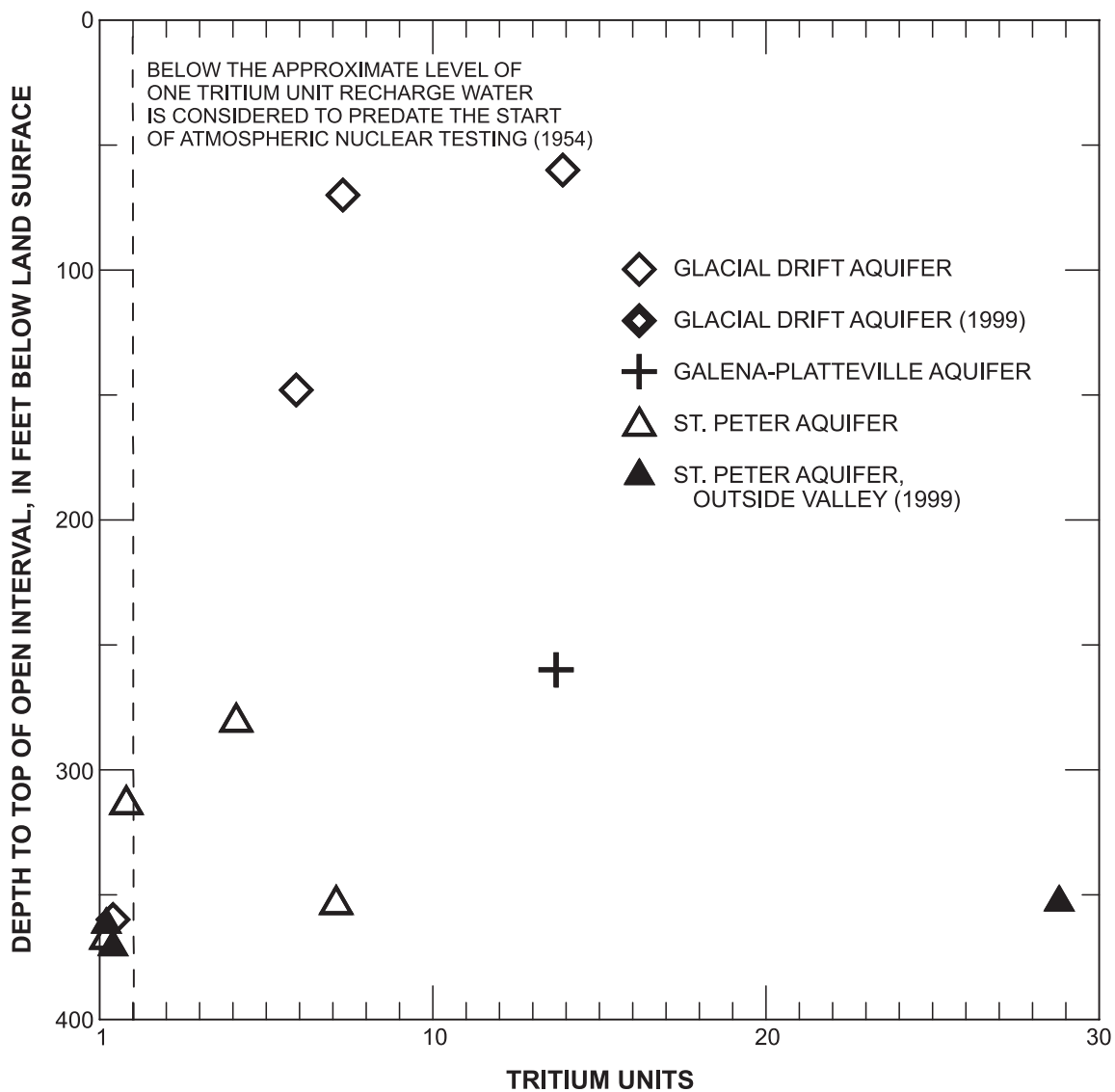


Figure 10. Relation between tritium levels in ground water and depth in aquifers in the vicinity of the Troy Bedrock Valley near Belvidere, 1999-2000.

Table 3. Tritium levels and concentrations of volatile organic compounds in aquifers in the vicinity of the Troy Bedrock Valley near Belvidere, Ill., 1999-2000

[ft bls, feet below land surface; µg/L, micrograms per liter; --, not detected; <, less than; ≤, less than or equal to]

Hydrogeologic unit to well is open¹: GD, glacial drift aquifer; GP, Galena-Platteville aquifer; GF, Glenwood confining unit; SP, St. Peter aquifer; CO, Cambrian-Ordovician aquifer system (St. Peter and deeper aquifers)

Well designation	Hydrogeologic unit to which well is open	Location in Troy Bedrock Valley and predominant units of glacial drift	Open or screened interval of well (ft bls)	Tritium units	Total concentrations of volatile organic compounds (µg/L)
21615	GD	northern part, till over sand	360-362	0.4	--
21296	GD	northern part, till over sand	60-100	13.9	--
² BMW9	GD	northern part, till over sand	³ 70-120	7.3	--
21541	GF-SP ⁴	northern part, till over sand	366-410	<.1	⁵ 11
22336	GF-SP ⁴	northern part, till over sand	312-400	.8	--
421755	GF-SP ⁴	northern part, till over sand	352-398	7.1	--
21408	GD	southern part, sand	148-150	5.9	--
21361	GP-GF ⁶	southern part, sand	260-330	13.7	--
21709	GP-SP ⁴	southern part, sand	279-390	4.1	--
² AGTG305SP	SP	outside of valley	352.8-357.8	28.8	21
² PCHG127SP	SP	outside of valley	370.7-375.7	.4	⁷ .5
² BMW8	CO	outside of valley	⁸ 362-1,390	≤.1	⁷ .6

¹ Hydrogeologic units described in figure 2.

² Sample collected during March 1999 (Mills and others, 2002).

³ 70-90 and 115-120 feet below land surface

⁴ Water is withdrawn primarily from the St. Peter aquifer.

⁵ Assumed to be byproducts of well disinfection: chloroform, bromodichloromethane.

⁶ Water is withdrawn primarily from the Galena-Platteville aquifer.

⁷ Assumed to be laboratory contaminant: methylene chloride.

⁸ 362-875 and 995-1,390 feet below land surface

Other data possibly contradict the data that indicate the Glenwood confining unit may be absent near wells 412755 and 21709. The tritium level in the sample from a similarly constructed well (22336) located across the valley from well 421755 ([fig. 1](#)) was less than 1 TU, thus, indicating “older” (recharged prior to onset of nuclear testing in 1954), ground water and the presence of the confining unit in this part of the valley. Also, low values of DO and Eh (0.21 mg/L and -79 mv, respectively) were recorded for a sample from a glacial drift well (21296) located within about 500 ft of 421755. If these values are representative of the glacial drift aquifer in the area of well 421755, then there may be other explanations for the elevated values recorded from well 421755 (pumping effects for example). Finally, tritium and other water-quality results from wells 421755 and 21709 may represent characteristics of well construction and near-well geology. The construction logs indicate the well casings terminate at the top of the Glenwood confining unit; thus, the wells may be grouted inadequately into the unit. At both locations, at least 200 ft of sand and gravel that generally composes an unconfined aquifer overlie the confining unit. These wells may withdraw some recently recharged water from the glacial drift aquifer. In summary, tritium results were inconclusive regarding the hydrostratigraphy of the valley.

Laboratory analysis included the major ions boron, calcium, chloride, fluoride, iron, magnesium, manganese, potassium, silica, sodium, and sulfate, as well as, acid neutralizing capacity (approximates alkalinity, as CaCO_3) and hardness ([appendix 2](#)). Ranges of major-ion concentrations by aquifer type are listed in [table 4](#).

Concentrations of calcium, magnesium, sulfate, and chloride were highest (greater than 82, 37, 58, and 10 mg/L, respectively) and concentrations of fluoride were lowest (less than 0.16 mg/L) in samples from shallow wells (less than 150 ft deep) open to the glacial drift aquifer (21296, 21408) ([figs. 1, 5](#)). The concentration of chloride also was comparatively high (15.5 mg/L) in the sample from one deep well (greater than 260 ft deep) open to the Galena-Platteville aquifer and Glenwood confining unit (21361) ([figs. 1, 5](#)). Well 21361 is within 100-400 ft of two highways, both of which are salted regularly during winter months. At and near this well, the overlying glacial drift aquifer is composed primarily of thick deposits (greater than 260 ft) of sand and gravel. The elevated concentration of chloride detected in the Galena-Platteville aquifer indicates that this aquifer and the overlying glacial drift aquifer are well connected hydraulically in this part of the valley.

Within the various aquifers in, near, and outside the valley, water type (calcium-bicarbonate) ([fig. 11](#)) and ionic concentrations were similar (Brown and Mills, 1995; Mills and others, 1998, 1999, 2002). Spatial trends in ionic constituents, where evident in the vicinity of the valley, are related primarily to the hydrogeology of the glacial drift aquifer. An elevated concentration of iron (1.640 mg/L) in one sample from the St. Peter aquifer (well 22336) was similar to concentrations in the overlying glacial drift aquifer, indicating that the two aquifers may be hydraulically connected in the northern part of the Troy Bedrock Valley. However, because the tritium level in this sample was less than 1 TU and concentrations of other constituents often contrasted those of the samples from the glacial drift aquifer, the aquifers likely are not connected. The elevated concentration of iron in the sample from the St. Peter aquifer and other samples more likely result from corrosion of the well casings and piping. Thus, major-ion chemistry provided no additional insight regarding the hydrostratigraphy of the valley.

VOC's (chloroform and bromodichloromethane) at low concentrations (9 and 2 $\mu\text{g/L}$, respectively) were detected in only one sample (well 21541) collected within the Troy Bedrock Valley ([appendix 5, table 3](#)); the well is open to the St. Peter aquifer beneath the northern part of the valley ([figs. 1, 5](#)). Although the Glenwood confining unit is thin (less than 12 ft) and weathered in this part of the valley, substantial hydraulic connection between the glacial drift and St. Peter aquifers, as suggested by the presence of VOC's in the St. Peter aquifer, is unlikely; about 300 ft of clay (with some lenses of sand) overlie the sandstone aquifer. The detected compounds more likely are by-products of well disinfection (chlorination of either the sampled well or a nearby well). There are no other reasonable sources for these compounds in this rural area and no VOC's have been detected in samples from nearby wells that have been sampled (Mills and others, 1998, 1999).

One sample was collected for analysis of trace elements from a well (21408) open to the glacial drift aquifer in the southern part of Troy Bedrock Valley ([appendix 3; figs. 1, 5](#)). Concentrations of most trace elements were similar to those detected in samples from parts of the aquifer outside the valley that are unaffected by contamination (Brown and Mills, 1995; Mills and others, 1998, 1999). Lead was detected at 1.7 $\mu\text{g/L}$. Lead detected in this sample likely is related to piping materials or particulate material distributed about the machine shop where the sample was collected.

Table 4. Range of concentrations of major ions and related properties in aquifers in the vicinity of the Troy Bedrock Valley near Belvidere, Ill., December 2000

[All concentrations in milligrams per liter; <, less than; ft bls, feet below land surface; >, greater than; na, not analyzed; ANC, acid neutralizing capacity]

Ion or property	Range of concentrations by primary aquifer type				
	Glacial drift (<150 ft bls) (2 samples)	Glacial drift (>150 ft bls) (1 sample)	Galena-Platteville (1 sample)	St. Peter (4 samples)	St. Peter (outside valley) ¹ (1-2 samples)
Boron ²	0.0124 – .0168	0.0176	0.0173	³ 0.0119 – .0261	na
Calcium	82.0 – 85.7	67.9	74.1	65.1 – 75.2	72 – 89
Chloride	10.4 – 12.5	1.33	15.5	2.66 – 8.46	.7 – 74
Fluoride	³ .14 – ³ .15	.25	.16	.16 – .24	.2 – .3
Iron ²	1.110 – 1.760	1.120	4.270	<.010 – 1.640	<.003 – .007
Magnesium	37.6 – 38.4	30.3	35.4	29.0 – 34.0	32 – 39
Manganese ²	.0416 – .0541	.0424	19.4	.0170 – .106	.016
Potassium	.75 – .94	.82	1.9	.71 – 1.7	1.5
Silica	16.2 – 17.2	17.2	13.0	16.5 – 18.5	11 – 14
Sodium	3.10 – 3.62	5.69	2.70	3.13 – 5.49	5.9 – 50
Sulfate	58.4 – 85.2	1.68	67.7	2.38 – 39.8	5.2 – 42
ANC ⁴	284 – 325	322	265	281 – 338	330 – 340
Hardness	360 – 370	290	330	280 – 320	310 – 380

¹ Data for wells about 1.5 miles east of valley from Mills and others (1998).

² Values converted from original concentrations reported in micrograms per liter.

³ Estimated value; below reporting limit

⁴ Approximates alkalinity. Samples analyzed for ANC are unfiltered and samples analyzed for alkalinity are filtered.

Troy Bedrock Valley near Belvidere, Ill.:

glacial drift aquifer (sand and gravel):

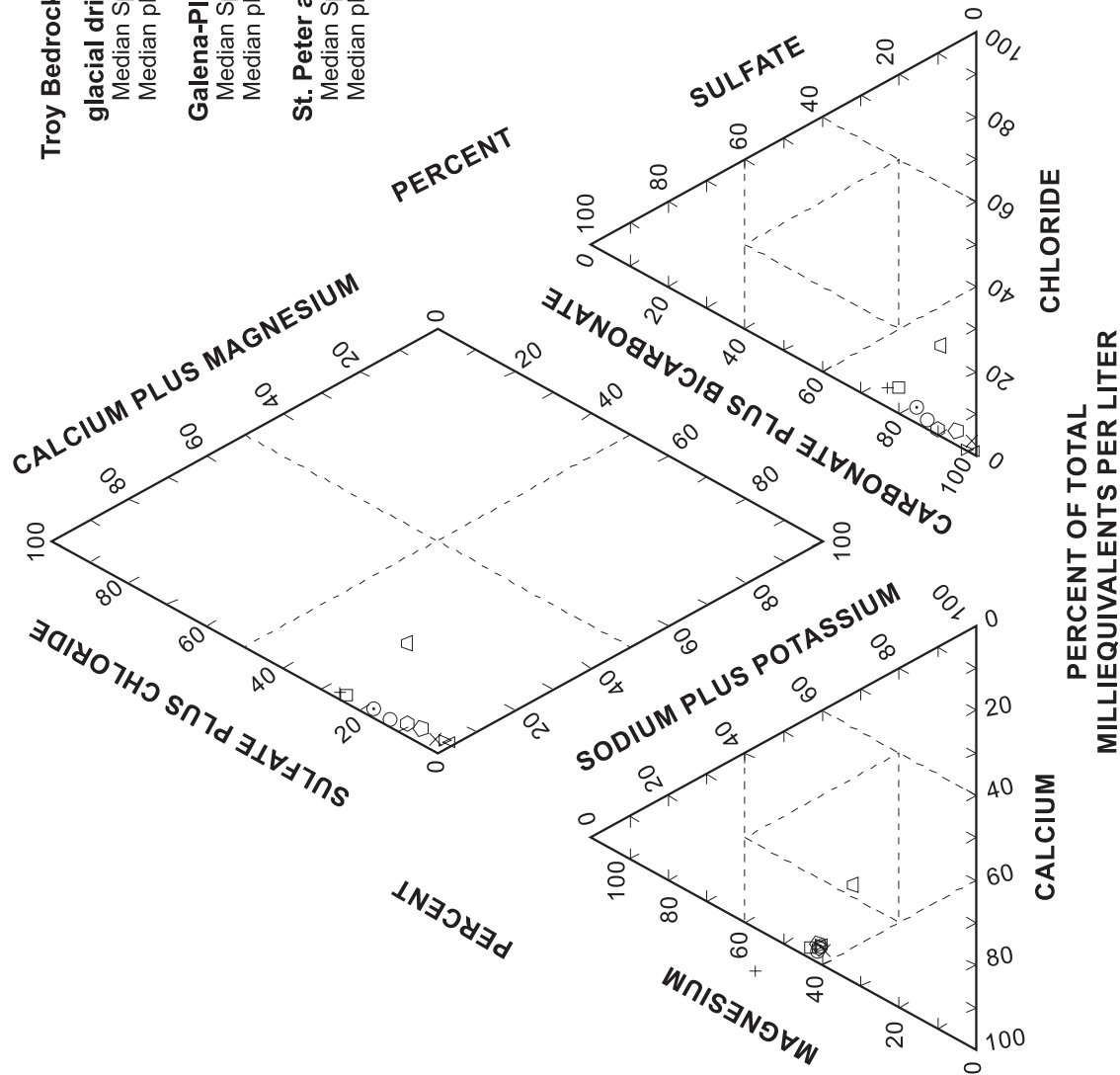
Median Specific Conductance: 678 microsiemens/centimeter
Median pH: 7.3

Galena-Platteville aquifer (dolomite):

Median Specific Conductance: 637 microsiemens/centimeter
Median pH: 7.5

St. Peter aquifer (sandstone):

Median Specific Conductance: 590 microsiemens/centimeter
Median pH: 7.2



EXPLANATION

WELL	PRIMARY AQUIFER	LOCATION IN VALLEY
△ 21615	glacial drift	northern
○ 21296	glacial drift	northern
+ 21408	glacial drift	southern
□ 21361	Galena-Platteville	southern
◇ 22336	St. Peter	northern
○ 421755	St. Peter	northern
× 21541	St. Peter	northern
◇ 21709	St. Peter	southern
▽ PCHG127SP	St. Peter	outside
△ AGTG305SP	St. Peter	outside

Figure 11. Relative concentrations of major ions in aquifers in the vicinity of the Troy Bedrock Valley near Belvidere, Ill., December 2000.

One sample was collected for analysis of radon-222 and radium-228 from a well (421755) open to the St. Peter aquifer in the northern part of the valley ([appendix 4](#); [figs. 1, 5](#)). The concentration of radon-222 was 263 pCi/L; radium-228 was not detected at the reporting limit of 1 pCi/L.

Federal and State regulatory standards have been established for the protection of public-water supplies. The standards do not apply to water withdrawn by privately owned wells, such as those included in this study. Constituent concentrations that are greater than those in the standards are indicative of impaired water quality. USEPA has established maximum contaminant levels (MCL's) for about one-half of the 19 trace elements, one-half of the 41 VOC's, and one of the 11 major ions and related constituents for which the water samples were analyzed (U.S. Environmental Protection Agency, 2002). Non-enforceable Federal standards, including secondary maximum contaminant levels (SMCL's), have been established for some of the analyzed constituents for which MCL's have not been established; these include five trace elements and four major ions and related constituents. Illinois has established Class I Potable Resource Groundwater Standards that are similar to the Federal MCL's (Illinois Pollution Control Board, 2001). In this report, reference to the Federal and State regulatory standards for samples collected from the private wells included in the study provides a basis for evaluating the general quality of water in the aquifers in and near the Troy Bedrock Valley and their potential as a future source for public supply.

Concentrations of most major ions and related constituents were less than present Federal (2002) and State (2001) regulatory standards. Concentrations of iron exceeded the SMCL (0.3 mg/L) in samples from five wells (21296, 21361, 21408, 21615, 22336); however, as previously discussed, the concentrations do not appear to be representative of the ground-water chemistry. Concentrations of manganese marginally exceeded the SMCL (0.05 mg/L) in samples from three wells (21361, 21408, 421755); as with the elevated concentrations of iron, these concentrations may not be representative of the ground-water chemistry. The total concentration of trihalomethane compounds (chloroform plus bromodichloromethane) in the one sample (well 21541) in which VOC's were detected was less than the MCL (100 µg/L). Concentrations of trace elements in the single well sample (21408) did not exceed Federal or State regulatory standards. Lead was

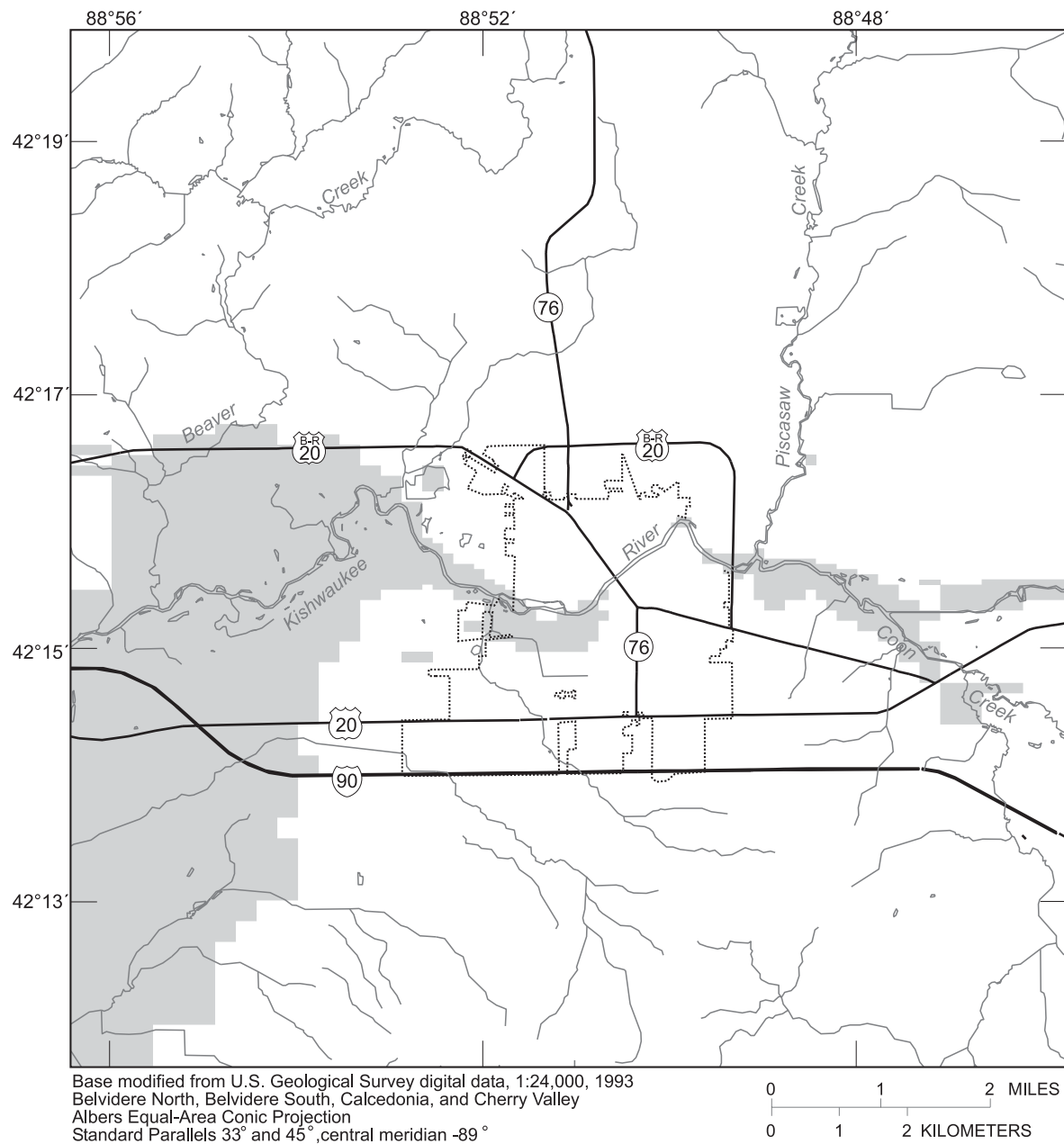
detected in the sample at a concentration of 1.17 µg/L; detectable levels of lead are considered to exceed the MCL Goal. As previously discussed, however, the detected lead concentration does not appear to be representative of the ground-water chemistry. The concentration of radon-222 in the single well sample (421755) was less than the proposed MCL of 300 pCi/L; radium-228 was not detected in that sample. The Illinois Class I Potable Resource Groundwater Standard for radium-228 is 20 pCi/L and the MCL for radium-226 plus radium-228 is 5 pCi/L.

EVALUATION OF GROUND-WATER FLOW BY PARTICLE TRACKING

Results of particle-tracking analysis of ground-water-flow patterns are described in the following sections. Selected directions of ground-water flow, discharge locations, and areas contributing recharge to the municipal wells and other private wells in Belvidere withdrawing greater than 1 Mgal/yr are described.

Ground-Water-Flow Directions

Within the study area, recharge to the ground-water-flow system primarily is from precipitation. As indicated by flow simulation (Mills and others, 2002), about 90 percent of recharge is to the aquifers overlying the Glenwood confining unit, with most of the flow discharging through the glacial drift aquifer to the Kishwaukee River and its tributaries. Recharge to the sandstone aquifers underlying the confining unit primarily occurs northwest of the study area, where the St. Peter Sandstone outcrops (in Wisconsin) or the Glenwood confining unit is absent in the deeply incised Rock Bedrock Valley (in Winnebago, Co., Ill.) (Young, 1992). Analysis of flow to different parts of the ground-water system indicated that about 25 percent of the volume of ground water within the glacial and Galena-Platteville aquifers outside the Troy Bedrock Valley flows into the valley. Simulated leakage indicates where water discharges from the Galena-Platteville aquifer to the overlying sand-and-gravel deposits that compose the glacial drift aquifer within the southern part of the Troy Bedrock Valley ([fig. 12](#)). About 70 percent of the flow entering the valley through the Galena-Platteville aquifer discharges to the Kishwaukee River and about 35 percent flows westward out of the study area.



EXPLANATION




-  DOWNWARD DISCHARGE FROM THE GLACIAL DRIFT AQUIFER (MODEL LAYER 1) TO THE GALENA-PLATTEVILLE AQUIFER (MODEL LAYER 2)
-  UPWARD DISCHARGE FROM THE GALENA-PLATTEVILLE AQUIFER (MODEL LAYER 2) TO THE GLACIAL DRIFT AQUIFER (MODEL LAYER 1)
-  BELVIDERE CITY LIMITS

Figure 12. Simulated distribution of leakage from the Galena-Platteville to the glacial drift aquifer in the vicinity of Belvidere, Ill., 1993.

Particle pathlines were tracked from 22 known or possible source areas for ground-water contamination (represented by 65 model cells) to discharge locations (figs. 1, 13). These areas included three Superfund sites (Parson's Casket Hardware, Belvidere Landfill No.1, MIG/DeWane Landfill), other landfills, industrial facilities and areas, and sites with leaking underground storage tanks where ground-water contamination has been documented (Brown and Mills, 1995).

For this analysis, particles were forward tracked from the top and bottom center of each selected cell in model layer 1 (representing the glacial drift aquifer). The particle placements approximate probable initial distributions of light non-aqueous phase liquids (LNAPL's—primarily petroleum hydrocarbons, such as benzene) and dense non-aqueous phase liquids (DNAPL's—primarily chlorinated solvents such as trichloroethene (TCE) and tetrachloroethene (PCE)) within ground water underlying Belvidere and vicinity. Limiting one particle to the center of each model cell is considered appropriate because of the scale of the regional model. The area of even the smallest model cell (250 ft by 250 ft) is substantially larger than most of the known or possible source areas for ground-water contamination. Because of the limitations associated with the scale of the regional model, including the inability to accurately define local hydrogeologic conditions, results of this analysis are considered most appropriate for general illustration of possible flow paths and discharge locations.

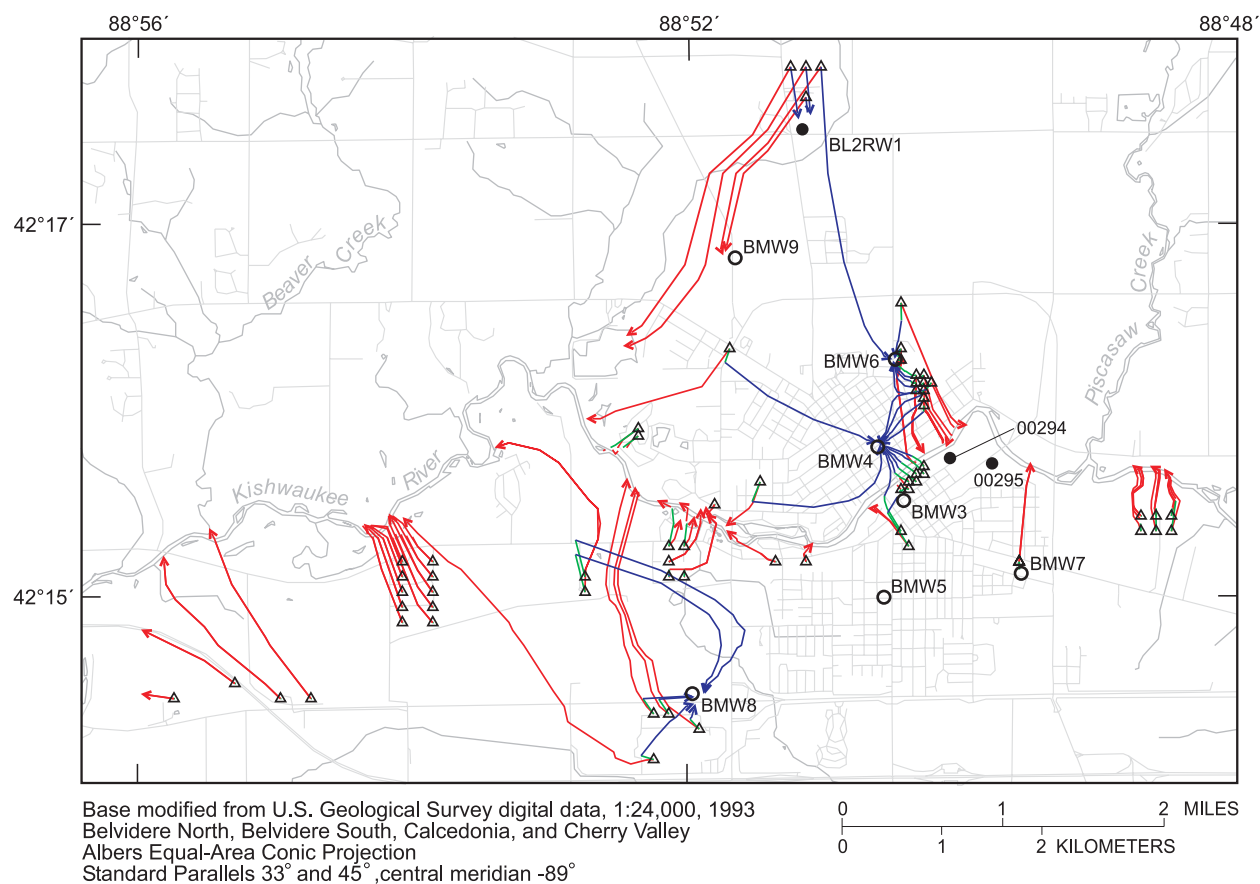
The following characteristics of the ground-water-flow field under ground-water-withdrawal rates of 1993 (table 2) are indicated from the simulated pathlines (fig. 13a):

- Flow from most source areas is restricted to the glacial drift aquifer and discharges to the Kishwaukee River or other surface-water bodies, such as the pond at the sand-and-gravel quarry about 2,000 ft north of the Kishwaukee River. Most of the source areas in and near Belvidere are within 1,500 ft of the river.
- Flow from some source areas moves from the glacial drift aquifer into the Galena-Platteville and sandstone aquifers of the Cambrian-Ordovician aquifer system, particularly where flow is affected by withdrawals from the Belvidere municipal wells. The percentage of

flow into each of the aquifers is not quantified, nor is the travel time; as discussed previously, only a small percentage of the total flow is expected to be to the bedrock aquifers that underlie the glacial drift aquifer.

- Flow from more than one source area discharges to municipal wells BMW3, BMW4, and BMW6 (fig. 1).
- Part of the flow originating from the National Sewing Machine facility (fig. 1) is northward beneath the Kishwaukee River in the bedrock aquifers, with discharge to municipal well BMW4. Flow southward from the Parson's Casket Hardware Superfund site and nearby source areas does not underflow the Kishwaukee River within the underlying bedrock aquifers. Apparently, flow into the bedrock aquifers near these source areas is affected more by withdrawals at nearby wells BMW4 and BMW6 than by well withdrawals south of the river (BMW3, 00294, 00295).
- Ground-water flow that originates in the glacial drift aquifer discharges to municipal well BMW8 (fig. 1), a well open exclusively to the St. Peter and deeper sandstone aquifers underlying the Glenwood confining unit. On the basis of tritium data, near-well geology, and historical water quality, well BMW8 has been considered invulnerable to contamination from aquifers overlying the confining unit (Mills and others, 2002). Previous flow simulation (Mills and others, 2002) indicates that leakage through the confining unit represents only a small percentage of total flow within the ground-water system. Thus, the likelihood of substantial contaminant loading to the St. Peter and deeper aquifers is considered to be small.
- Discharge to municipal wells BMW5 and BMW7 from possible source areas in and near Belvidere is not indicated by the analysis and is possibly related to one or more of the following factors: distance between the wells and source areas, relative rates of withdrawal and location of other high-capacity wells, relative depths of the wells and surface casings, and low hydraulic conductivity of the deposits that compose the overlying glacial drift aquifer.

A



EXPLANATION

SIMULATED PARTICLE PATHLINE -- Direction of flow is away from the source area

- Red pathway in the glacial drift aquifer (model layer 1)
- Green pathway in the Galena-Platteville aquifer (model layer 2)
- Blue pathway in the sandstone aquifers of the Cambrian-Ordovician aquifer system (model layer 4)

Vertical pathway in the Glenwood confining unit (model layer 3)
 not shown

○ BMW3 BELVIDERE MUNICIPAL WELL AND DESIGNATION

● 00295 PRIVATE WELL WITHDRAWING GREATER THAN 1,000,000 GALLONS PER YEAR AND DESIGNATION

△ CENTER OF MODEL CELL THAT INCLUDES A CONTAMINANT-SOURCE AREA -- Particles placed at the top (water table) and bottom (bedrock surface) center of the cells that represent the glacial drift aquifer (model layer 1)

Figure 13. Simulated particle pathlines from possible contaminant-source areas to discharge locations in the vicinity of Belvidere, Ill., (A) 1993 and (B) 2000.

After 1996, flow patterns in the vicinity of municipal wells BMW2 and BMW3 likely differed from those in 1993 ([fig. 13a](#)). During the 1993 model-calibration period, well BMW2 was not in use and well BMW3 was used sparingly ([table 2](#)). During 1996, these wells were returned to full use. For the municipal system, total withdrawals were greater in the years after 1996 than in 1993. As an example, total withdrawals were 22 percent greater in 2000 than in 1993 (although withdrawals from wells BMW4 and BMW6 were about 20 percent less) (J.A. Grimes, Belvidere Water Department, written commun., 2001). Figure 13b illustrates possible ground-water-flow paths under conditions of municipal- and private-well withdrawal during year 2000. The simulation does not account for other possible differences between hydrogeologic conditions in 1993 and 2000. Recharge likely was greater in 1993 than 2000, because of the substantial amount of precipitation in 1993 (greater than 150 percent of average) (Dana Kolpin, U.S. Geological Survey, written commun., 1993). Although not rigorously researched, withdrawals from private high-capacity wells in the area seem to be similar during the two simulation periods.

The following characteristics of the ground-water-flow field under ground-water-withdrawal rates of 2000 ([table 2](#)) are indicated from the simulated pathlines ([fig. 13b](#)):

- In response to the substantial increase in withdrawals, newly established flow paths indicate discharge to municipal wells BMW2 and BMW3.
- As simulated using 1993 withdrawal rates, ground-water flow continues beneath the Kishwaukee River. However, in 1993, flow was within the Galena-Platteville aquifer and underlying sandstone aquifers from the area of the National Sewing Machine facility ([fig. 1](#)) to municipal well BMW4. In 2000, flow from the National Sewing Machine facility discharges to nearby wells municipal BMW2 and BMW3. Underflow is restricted to the sandstone aquifers, represented exclusively by discharge from the area of the Parson's Casket Hardware Superfund site to well BMW2; in 1993, all flow in sandstone aquifers beneath this site discharged to wells BMW4 and BMW6.
- In 1993, flow from the eastern part of an industrial area on the western limits of Belvidere and from the area of the MIG/DeWane Landfill Superfund site ([fig. 1](#)) discharged exclusively to

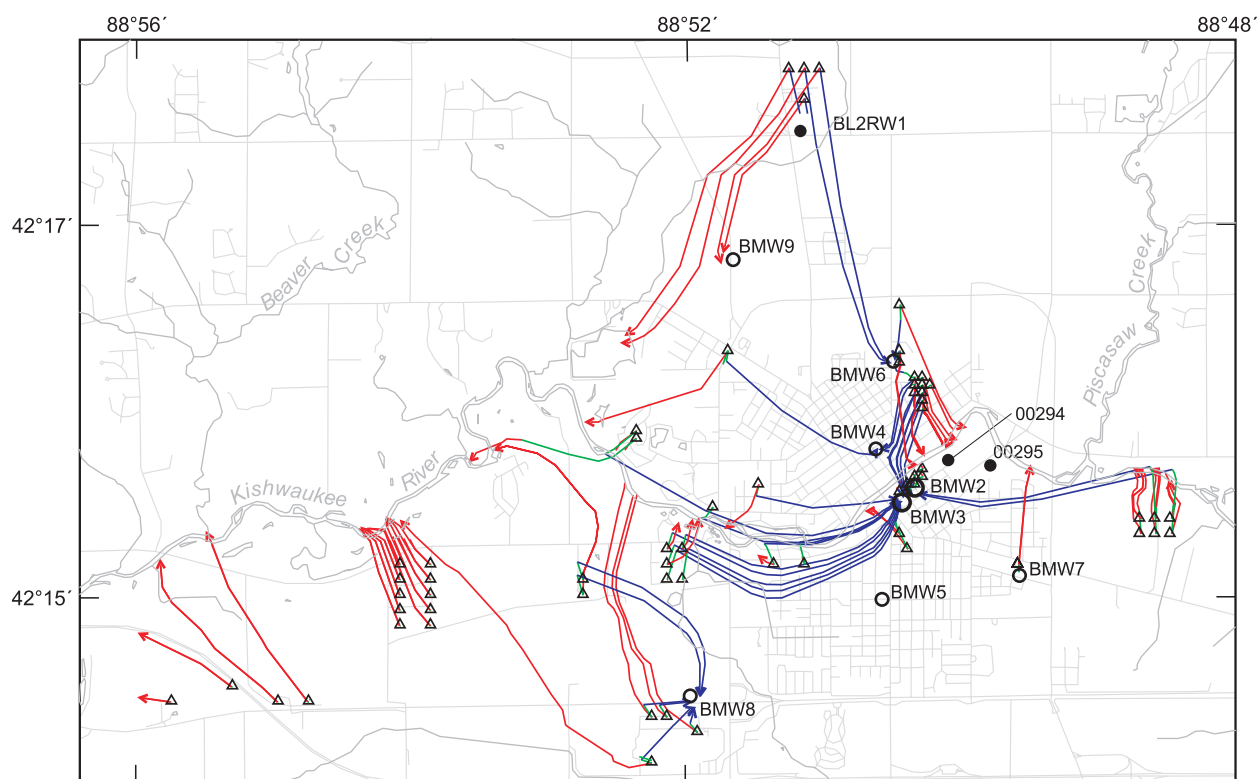
the nearby Kishwaukee River through the glacial drift and Galena-Platteville aquifers. In 2000, some of the flow that discharged into the Kishwaukee River is diverted into the underlying sandstone aquifers. This diverted flow discharges to municipal wells BMW2 and BMW3, located almost 2 mi from the two contaminant-source areas.

Simulated ground-water-flow patterns, as simulated by particle tracking using well-withdrawal rates for 1993 and 2000, generally are substantiated by available water-quality data. Contaminant plumes have been mapped from many of the identified source areas, including the Parson's Casket Hardware, MIG/DeWane Landfill, and Belvidere Landfill No. 1 Superfund sites ([fig. 1](#)). VOC's, particularly TCE and PCE, have been detected consistently in samples from municipal wells BMW2 and BMW3 and intermittently in samples from municipal wells BMW4 and BMW6 ([appendix 5](#); Mills and others 1999, 2002).

Particle-tracking analysis indicates that additional, unidentified contaminant-source areas may be present in Belvidere. TCE and PCE have been detected intermittently in samples from municipal well BMW5 ([appendix 5](#); Mills and others, 1999, 2002). In the analysis, flow from no known or possible source areas that are included discharges to this well. Simulation uncertainties (estimation of the magnitude and spatial distribution of hydraulic conductivity and recharge, for example) also may account for the inconsistency between particle-tracking results and water-quality data from well BMW5. Lack of accounting for preferential flow through bedding-plane partings and fractures in the Galena-Platteville aquifer to the wells in the model likely contribute to that uncertainty.

Particle-tracking analysis also indicates that, in the future, the quality of water withdrawn by municipal wells BMW8 and BMW9 possibly could be affected by contaminants released to ground water from some of the known or possible source areas in and near Belvidere. As of December 2000, few, if any, VOC's had been detected in samples from these wells (the few intermittent detections at trace-level concentrations are attributed to contamination during handling or analysis of the samples) ([appendix 5](#); Mills and others, 1999, 2000). The present quality of water withdrawn by the wells possibly relates to the type of contaminant that has been released. For example, LNAPL-related compounds (benzene and others) have been identified in ground water at an industrial facility adjacent to municipal well BMW8 (GZA GeoEnvironmental, Inc., 1993).

B



Base modified from U.S. Geological Survey digital data, 1:24,000, 1993
Belvidere North, Belvidere South, Calcedonia, and Cherry Valley
Albers Equal-Area Conic Projection
Standard Parallels 33° and 45°, central meridian -89°

0 1 2 MILES
0 1 2 KILOMETERS

EXPLANATION

SIMULATED PARTICLE PATHLINE -- Direction of flow is away from the source area

- Red pathway in the glacial drift aquifer (model layer 1)
- Green pathway in the Galena-Platteville aquifer (model layer 2)
- Blue pathway in the sandstone aquifers of the Cambrian-Ordovician aquifer system (model layer 4)

Vertical pathway in the Glenwood confining unit (model layer 3)
not shown

○ BMW3 BELVIDERE MUNICIPAL WELL AND DESIGNATION

● 00295 PRIVATE WELL WITHDRAWING GREATER THAN 1,000,000 GALLONS PER YEAR AND DESIGNATION

△ CENTER OF MODEL CELL THAT INCLUDES A CONTAMINANT-SOURCE AREA -- Particles placed at the top (water table) and bottom (bedrock surface) center of the cells that represent the glacial drift aquifer (model layer 1)

Figure 13. Simulated particle pathlines from possible contaminant-source areas to discharge locations in the vicinity of Belvidere, Ill., (A) 1993 and (B) 2000—Continued.

These compounds are likely to continue moving away from well BMW8 in the glacial drift aquifer or shallow parts of the Galena-Platteville aquifer. Should a DNAPL be released at this or other nearby facilities, the quality of water withdrawn by well BMW8 possibly could be affected. The present quality of water withdrawn by the wells also may relate to ground-water-flow velocities and distances between the source areas and municipal wells. Given sufficient time, contaminants possibly released from the source areas may be withdrawn by the wells.

Flow paths from some source areas may not be well delineated by the particle-tracking analysis. Pathways within bedding-plane partings and fractures in the Galena-Platteville aquifer could differ from those simulated on the assumption of matrix flow. Flow in the glacial drift aquifer from the landfill about 1 mi north of Belvidere ([fig. 1](#)) and other areas could discharge periodically to intermittent streams that were not included in the model. Flow in the glacial drift aquifer from source areas on the eastern edge of the study area, appears to discharge to the model boundary where water levels are specified. Finally, not all present or possible contaminant-source areas in the vicinity of Belvidere may be identified.

Areas Contributing Recharge to Wells

Areas contributing recharge to the Belvidere municipal wells and nearby private wells withdrawing greater than 1 Mgal/yr are shown in [figure 14](#). The areas were simulated using 1993 withdrawal rates ([table 2](#)), the rates applied during the model calibration period.

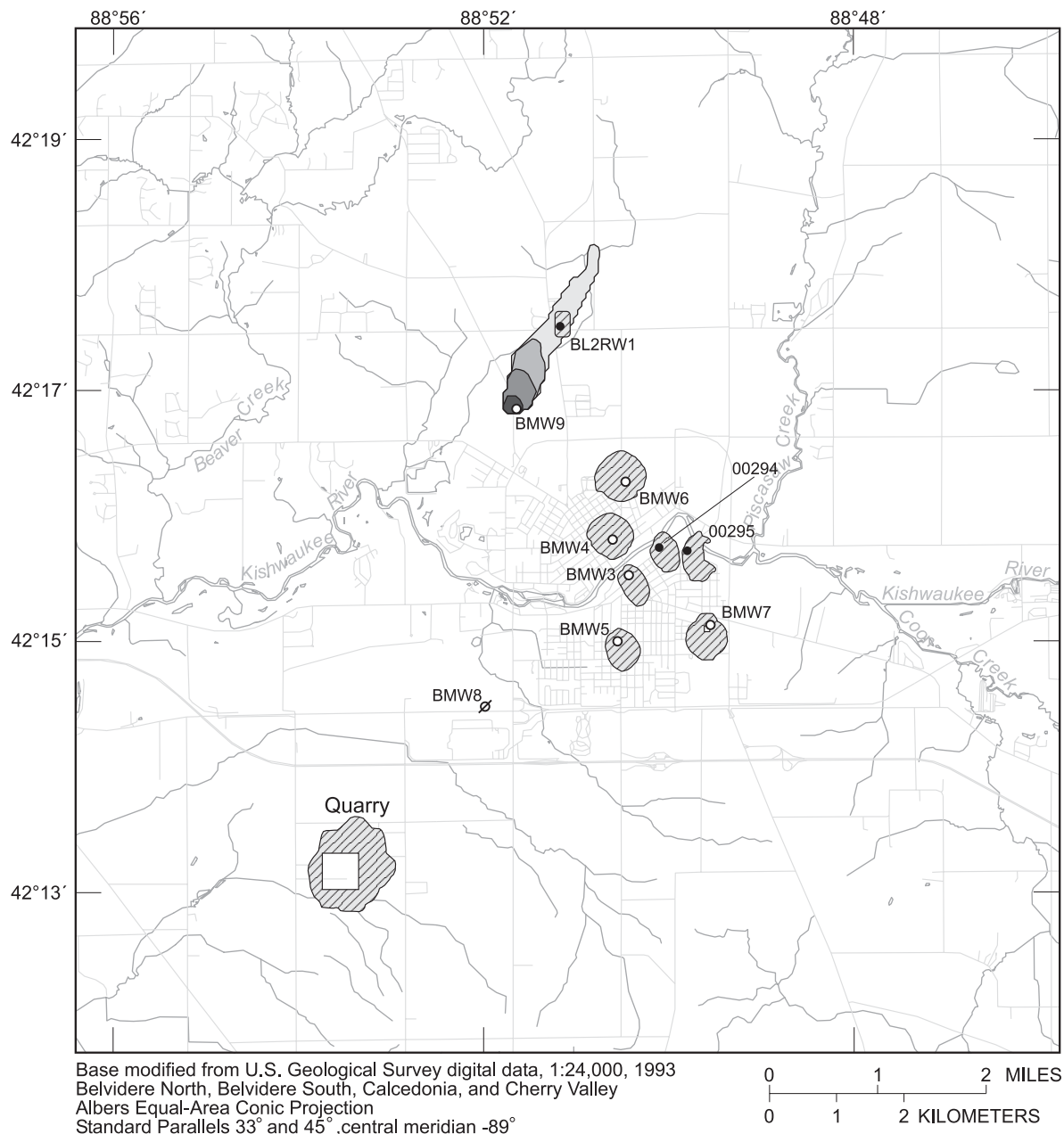
Areas contributing recharge to wells for finite periods of time are affected by effective porosity. Effective porosity has a linear effect on the travel time of a particle, but has no effect on the particle pathlines. An increase in the effective porosity decreases the area associated with each travel time. Estimated effective porosity distributions of 0.20, 0.01, 0.01, and 0.25 were assigned to the glacial drift aquifer (model layer 1), the Galena-Platteville aquifer (model layer 2), the Glenwood confining unit (model layer 3), and the sandstone aquifers of the Cambrian-Ordovician aquifer system (model layer 4), respectively.

Areas contributing recharge to municipal well BMW9, open to the unconfined glacial drift aquifer (model layer 1), were delineated by back tracking particles from the well to the water table; the areas

represent ground-water travel times in periods of 0-1, 1-5, 5-10, and 10-25 years ([fig. 14](#)). The contributing area represented by travel times longer than 25 years is larger than that shown in figure 14 (generally extending farther northward). Simulated ground-water flow from the landfill about 2 mi north of Belvidere ([fig. 1](#)) reaches well BMW9 in less than about 25 years. As of December 2000, no contaminants had been detected in samples from well BMW9 ([appendix 5](#); Mills and others, 1999, 2002). Operations at the landfill began in 1974 (Ecology and Environment, 1990).

Areas contributing recharge to the selected wells open to the Cambrian-Ordovician aquifer system (model layers 2-4) were delineated differently from well BMW9, which is open to the glacial drift aquifer (model layer 1). The areas were delineated by back tracking particles from the full length of the interval of each well open to the Galena-Platteville aquifer (model layer 2) to the base of the glacial drift aquifer. This approach is illustrated, in part, in [figure 7b](#). The number of particles that were assigned to a well was proportional to the withdrawal rate, so a well withdrawing 0.5 Mgal/d had five times as many particles as a well withdrawing 0.1 Mgal/d. Discharge per particle was about 0.14 gal/min, with about 3 Mgal/d distributed over 15,200 particles. Contributing areas shown in figure 14 for the selected municipal (BMW3-BMW7) and private (BL2RW1, 294, 295, Quarry) wells represent the entire area for each well regardless of time.

The above-described approach provides appropriate estimates of areas contributing recharge and ground-water travel times for the wells open to the Cambrian-Ordovician aquifer system, given the hydrogeology and water quality in the vicinity of the supply wells. High concentrations of TCE (1,300 µg/L) detected near the top of the Galena-Platteville aquifer (the uppermost unit of the bedrock aquifer system) at the Parson's Casket Hardware Superfund site (Mills, 1993) ([fig. 1](#)) indicate DNAPL's likely pool along the contact between the glacial drift and Galena-Platteville aquifers. Detection of TCE (and a similar chlorinated solvent, PCE) in water samples from four municipal wells (BMW2, BMW3, BMW4, BMW6) located within 0.25 to 0.75 mi of the Parson's Casket Hardware Superfund site also indicates that DNAPL's may pool at the surface of the Galena-Platteville aquifer. As the solvents dissolve in ground water, they move from the pool locations into and through the Galena-Platteville aquifer to area wells by way of the network of inclined



EXPLANATION

AREA CONTRIBUTING RECHARGE TO OPEN INTERVAL
 OF WELL IN GLACIAL DRIFT AQUIFER --
 0-1 year
 Greater than 1-5 years
 Greater than 5-10 years
 Greater than 10-25 years



AREA CONTRIBUTING RECHARGE TO OPEN INTERVAL
 OF WELL IN GALENA-PLATTEVILLE AQUIFER FROM
 BASE OF GLACIAL DRIFT AQUIFER -- Maximum
 estimated travel times range from 2 to 67 years (see
 figure 15 for further explanation)

BMW3 BELVIDERE MUNICIPAL WELL
 AND DESIGNATION

00295 PRIVATE WATER-SUPPLY WELL
 WITHDRAWING GREATER THAN
 1,000,000 GALLONS PER YEAR
 AND DESIGNATION

BMW8 BELVIDERE MUNICIPAL WELL OPEN
 TO CONFINED SANDSTONE
 AQUIFERS OF THE CAMBRIAN-
 ORDOVICIAN AQUIFER SYSTEM
 AND DESIGNATION

Figure 14. Simulated travel-time-related areas contributing recharge to municipal wells and private wells withdrawing greater than 1,000,000 gallons per year in the vicinity of Belvidere, Ill., 1993.

fractures and subhorizontal bedding-plane partings (Mills and others, 2002).

In much of the area where the Belvidere municipal wells are located, permeable deposits of sand and gravel (K_h up to 370 ft/d) that generally are less 40 ft thick overlie the less permeable (K_h about 0.05 ft/d) bedrock aquifer (Mills and others, 2002). Such conditions contribute to rapid vertical movement of DNAPL's through the glacial drift aquifer and pooling along the surface of the bedrock aquifer. DNAPL sources, such as the chlorinated solvents present in the aquifers underlying Belvidere, move independently of the prevailing direction of ground-water flow because of the density contrast between the sources and ground water. Areas contributing recharge to wells in which such conditions are present cannot be simulated reasonably by conventional methods based solely on prevailing directions ground-water flow throughout the ground-water system.

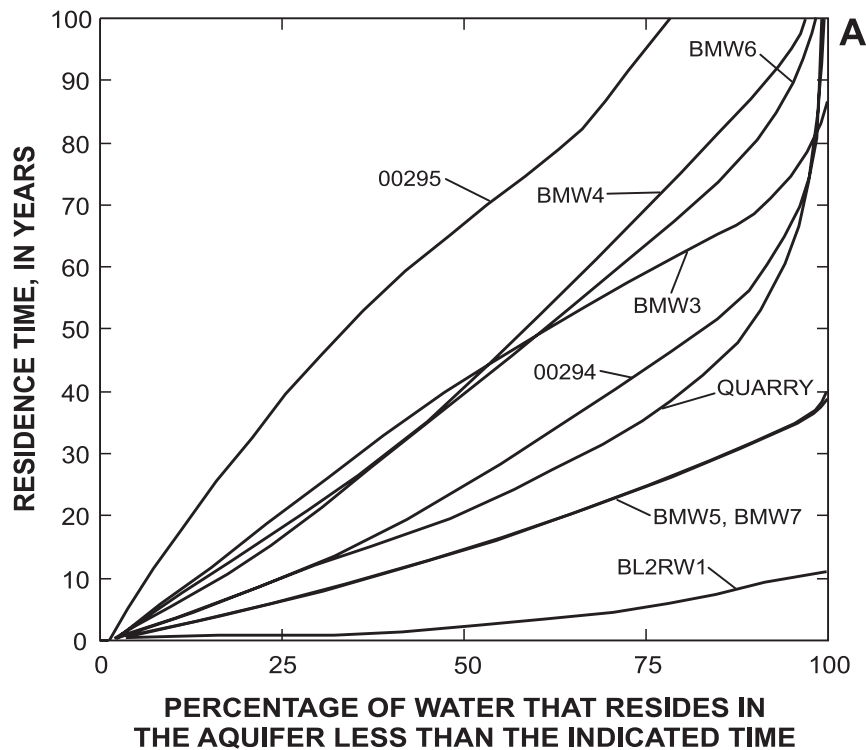
Ground water withdrawn from the Galena-Platteville aquifer is a mixture of waters with a range of residence times in the aquifer (fig. 15a). Residence time in the aquifer is a surrogate for contaminant travel time because the simulation represents dissolved DNAPL contaminants introduced to ground water near the top of the aquifer. The residence time for water that enters near the top of the aquifer is less than a year; the longest residence times are for water that enters a well near the base of the aquifer. For example, simulated residence times for water that is withdrawn from the Galena-Platteville aquifer by municipal well BMW3 range from about 0 to about 85 years with an average residence time of about 40 years. Residence times in the aquifer were estimated with the effective porosity of the aquifer assumed to be 0.01.

Simulated residence times increase as effective porosity increases. Figure 15b contrasts residence times for 50 percent of the water withdrawn from the Galena-Platteville aquifer using porosity estimates of 0.01 and 0.20. Such a contrast is important, because of the uncertainty associated with estimating the effective porosity of the aquifer. Using the conservative porosity estimate of 0.01, average residence times range from about 2 years for well BL2RW1 to about 70 years for well 00295. Well BL2RW1 is open to only 22.5 ft of the aquifer and is located at the edge of the Troy Bedrock Valley, where the aquifer is only about 40 ft thick (figs. 1, 5). The withdrawal rate (0.17 Mgal/d) at well 00295

is one of the lowest for the wells included in the simulation (table 2) and the open interval within the Galena-Platteville aquifer is one of the greatest (257 ft).

If the movement of ground water (and (or) contaminants) from near land surface to the top of the Galena-Platteville aquifer is rapid, as assumed previously, then the simulation-based estimates of residence times of water within the Galena-Platteville aquifer (model layer 2) can be compared reasonably to water-quality-based estimates of travel times of water from near land surface to various depths within the Galena-Platteville aquifer. Detection of methyl *tertiary*-butyl ether (MTBE) in water samples from municipal well BMW4 (Richard Cobb, Illinois Environmental Protection Agency, written commun., 2001), open to the lower half of the Galena-Platteville aquifer, indicates that in this part of the study area travel times between near land surface and the mid-part of the Galena-Platteville aquifer may be less than about 16 years (MTBE was first used as a gasoline additive in the United States in 1979). Tritium levels in samples from area wells open to the Galena-Platteville aquifer indicate that water withdrawn from almost all parts of the aquifer is less than about 46 years old. Relative ages of ground water in the aquifers underlying the area, as based on detections of tritium and MTBE, are shown in figure 6. These ages compare favorably with the travel times simulated for water withdrawn from the Galena-Platteville aquifer by the municipal and private wells, using a porosity estimate of 0.01 (fig. 15).

Areas contributing recharge and travel times for municipal well BMW8 were not estimated because the well is cased into the Glenwood unit and withdraws water primarily from the confined St. Peter and deeper sandstone aquifers of the Cambrian-Ordovician aquifer system. Under these conditions, travel-time estimates from areas contributing recharge to wells are considered unreasonable. Travel times to unconfined source waters near land surface would be too long to be useful for water-management purposes and likely to be highly uncertain. Should the Glenwood confining unit be completely eroded in the Troy Bedrock Valley (about 2 mi west of the well), flow between the unconfined and hydraulically connected glacial drift and St. Peter aquifers might possibly contribute recharge to well BMW8 within a reasonable time frame. Consequently, the simulation of contributing areas and travel times for this well might be reasonable.



B

Well	Porosity, dimensionless		
	0.01	0.20	
BL2RW1	2	50	Residence time of 50 percent of the water, in years
BMW6	40	800	
BMW4	40	800	
00294	20	500	
00295	70	1,000	
BMW3	40	800	
BMW7	10	300	
BMW5	10	300	
QUARRY	20	400	

Figure 15. Simulated residence time of water in the Galena-Platteville aquifer (model layer 2) withdrawn by selected wells in the vicinity of Belvidere, Ill., (A) distribution of residence times, using a porosity of 0.01 and (B) residence times of 50 percent of the water, using porosities of 0.01 and 0.20.

SUMMARY

The U.S. Geological Survey, U.S. Environmental Protection Agency, and Illinois Environmental Protection Agency began a study of the hydrogeology, flow system, and distribution of contaminants in the aquifers underlying Belvidere, Ill., and vicinity in 1992. As part of the study, the ancestral Troy Bedrock Valley, located about 1.5 mi west of Belvidere, was identified as an important part of the ground-water-flow system that (1) may contribute substantially to recharge and possible future contamination of the underlying St. Peter aquifer (sandstone) and (2) has greater capacity than currently used for public-water supply (Mills and others, 2002). The St. Peter aquifer is a regionally important source for public-water supply; throughout most of northern Illinois, the overlying Glenwood unit confines the aquifer. Because few deep wells open to the St. Peter aquifer are present in the valley to provide necessary lithologic and stratigraphic information, the presence of the confining unit in the valley is uncertain; 260-ft-thick deposits of sand and gravel that infill the southern part of the valley may directly overlie the St. Peter aquifer. Tritium and other water-chemistry data were collected from eight wells in and near the valley to possibly further delineate areas where the confining unit may be absent; the data also provide baseline water-quality information for an area expecting changes in land use and increases in water withdrawal. Additionally as part of the study, particle-tracking analysis was done using a previously developed flow model of the vicinity of Belvidere to (1) identify possible discharge locations of ground water and contaminants and (2) delineate areas contributing recharge to the Belvidere municipal wells and other high-capacity wells in the area.

This report presents and interprets water-chemistry data collected during December 2000, briefly describes the available ground-water-flow model, and presents results of particle-tracking analysis. Analyses of tritium, major ions, volatile organic compounds, and other water-chemistry data were inconclusive regarding delineation of where the Glenwood confining unit may be absent within the Troy Bedrock Valley. On the basis of tritium data, water in the St. Peter aquifer appears to have recharged after 1954 in samples from two of four wells. Recharge after 1954 suggests that the confining unit may be absent near these wells. Water-chemistry data from the two wells and nearby wells do not consistently support and may contradict this conclusion; the wells may withdraw some water from the glacial drift aquifer, as the wells

are cased only into the uppermost part of the confining unit. Concentrations of iron, manganese, and lead exceeded maximum contaminant levels (MCL's) in five or less samples, but materials associated with the water-distribution systems appear to contribute to the elevated concentrations above natural levels.

Particle-tracking analysis indicates that most ground-water flow beneath known and possible contaminant-source areas discharges from the glacial drift aquifer to the river. Most of the source areas are in or near Belvidere and are within 1,500 ft of the river. The analysis also indicates the possibility that in parts of the study area, some ground water does not discharge to Kishwaukee River, but flows beneath the river in the underlying carbonate Galena-Platteville aquifer. Ground water is estimated to travel over 1 mi in the glacial drift aquifer to municipal well BMW9 in less than 25 years. Residence (travel) times of ground water from the base of the glacial drift aquifer to the six municipal wells (BMW2-BMW7) open, in part, to the Galena-Platteville are estimated at about 10 to 40 years. Because fractures in this aquifer are unaccounted for in the flow model, actual areas contributing recharge are likely larger and travel times faster than those simulated for most of the municipal wells. Tritium data indicate that travel times from land surface to the deepest parts of the Galena-Platteville aquifer generally are less than 46 years. Detection of methyl *tertiary*-butyl ether (MTBE) in samples from municipal well BMW4, open to the Galena-Platteville aquifer, indicates that travel times to municipal wells open the upper part of the aquifer (BMW2-BMW6) may be less than 16 years. The water-quality-based estimates of travel time generally are consistent with the estimates from particle-tracking analysis.

Results of particle-tracking analysis described in this report are limited by the assumptions of the applied numerical model. Delineation of areas contributing recharge to wells and travel times are affected most by the accuracy of the estimates of hydraulic conductivity and by estimates of effective porosity. Errors are expected to be greatest for simulated travel times within the Galena-Platteville aquifer, because of the degree of uncertainty for the estimates of hydraulic conductivity and porosity are greatest for this fractured-carbonate unit. Although the uncertainties and limitations associated with numerical models, including this of Belvidere and vicinity, should not be ignored, such models provide invaluable new insight and understanding of ground-water-flow systems.

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APPENDIXES

Appendix 1. Field-determined characteristics of ground water at selected wells in the vicinity of Belvidere, Ill., December 2000.

[°C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 Celsius; mv, millivolts; mg/L, milligrams per liter; NTU, nephelometric turbidity unit; --, no data; clr, clear; clr/cldy, clear to cloudy; cldy, cloudy]

Hydrogeologic unit to which well is open: GD, glacial drift aquifer; GP, Galena-Platteville aquifer; GF, Glenwood confining unit; SP, St. Peter aquifer; OR, Ordovician aquifer system (Galena-Platteville and St. Peter aquifers); CO, Cambrian-Ordovician aquifer system (Galena-Platteville, St. Peter, Ironton-Galesville, and (or) Elmhurst-Mt. Simon aquifers)

Well designation	Sample date	Hydrogeologic unit to which well is open	pH (standard unit)	Temperature (°C)	Specific conductance (µS/cm)	Oxidation-reduction potential (Eh) (mv)	Dissolved oxygen (mg/L)	Turbidity (NTU)
21296	12-12-00	GD	7.21	11.6	690	-79	0.21	clr
21361	12-12-00	GP-GF	7.53	10.5	637	-175	.26	clr
21408	12-11-00	GD	7.40	--	678	--	.16	clr
21541	12-13-00	GF-SP	7.26	11.2	601	--	.20	clr/cldy
21615	12-13-00	GD	7.32	11.0	558	78	.31	clr
21709	12-12-00	GP-SP	7.12	11.6	626	-5	.31	clr
22336	12-12-00	GF-SP	7.38	11.3	543	-121	.26	clr
421755	12-12-00	GF-SP	7.23	10.6	579	184	1.75	clr
AGTG305GPS	04-21-98	GP	6.85	11.7	683	42	--	clr
do.	03-22-99	GP	7.07	11.4	833	--	.04	clr
do.	12-14-00	GP	7.11	11.4	896	--	.14	clr
AGTG305GPD	04-20-98	GP	7.02	11.1	657	46	.06	0.17
do.	03-22-99	GP	7.38	11.4	489	14	.08	cldy
do.	12-14-00	GP	7.11	11.1	921	--	.13	clr/cldy
AGTG305SP	04-20-98	SP	7.05	11.0	837	185	--	.88
do.	03-22-99	SP	7.17	11.6	539	131	.13	clr
do.	12-13-00	SP	6.96	11.1	752	--	.19	clr
BMW2	04-28-98	CO	6.74	12.2	1,140	120	--	clr
do.	03-24-99	CO	6.93	11.9	1,103	98	1.05	clr
do.	12-15-00	CO	7.05	11.7	1,145	--	--	clr
BMW3	04-20-98	CO	6.88	13.7	1,073	142	--	clr
do.	03-24-99	CO	6.95	13.8	1,142	110	3.00	clr
do.	03-24-99	CO	7.00	13.3	1,251	--	2.81	clr
BMW4	04-27-98	CO	7.01	11.8	772	25	--	clr
do.	03-22-99	CO	7.38	11.6	494	84	--	clr
do.	12-15-00	CO	7.15	12.0	730	--	3.50	clr
BMW5	04-20-98	OR	6.99	11.8	712	2	--	clr
do.	03-23-99	OR	7.14	11.5	621	0	--	clr
do.	12-15-00	OR	7.10	11.8	834	--	.26	clr
BMW6	03-23-99	CO	7.18	11.2	558	34	--	clr
do.	12-13-00	CO	7.21	11.4	704	--	1.37	clr
BMW7	03-23-99	CO	7.29	12.6	460	0	--	clr
do.	12-15-00	CO	7.10	11.8	834	--	.26	clr
BMW8	03-23-99	CO	7.26	12.1	446	-12	--	clr
BMW9	03-24-99	GD	7.29	10.4	614	-24	1.04	clr
do.	12-15-00	GD	7.34	10.6	673	--	1.12	clr
PCHG128GPS	04-21-98	GP	6.85	11.5	657	-2	--	clr
do.	03-22-99	GP	7.14	11.3	676	-36	--	clr
do.	12-15-00	GP	7.14	11.0	722	--	2.25	clr
PCHG128GPD	04-21-98	GP	7.00	10.8	655	6	.09	.2
do.	03-23-99	GP	7.22	11.4	599	-18	.06	clr
do.	12-14-00	GP	7.21	10.9	650	--	.11	clr
PCHG436B	04-20-98	GP	6.97	11.7	¹ 982	177	--	clr
do.	² 12-14-00	GP	7.26	11.1	1,019	--	--	clr
PCHG436GPS	04-27-98	GP	7.05	11.9	530	-14	--	cldy
do.	12-14-00	GP	7.22	10.8	572	--	.13	clr/cldy

¹ Sampled with a peristaltic pump; air in flow-through cell results in values fluctuating by about +/- 30 microsiemens per centimeter.

² Water sample was collected with a peristaltic pump; measurements made from grab sample in bucket.

Appendix 2. Concentrations of major ions in ground water at selected wells in the vicinity of Belvidere, Ill., December 2000.

[All concentrations of major ions represent dissolved fraction; ANC, acid neutralizing capacity represents total fraction and approximates alkalinity; µg/L, micrograms per liter; mg/L, milligrams per liter; <, less than]

Hydrogeologic unit to which well is open: GD, glacial drift aquifer; GP, Galena-Platteville aquifer; GF, Glenwood confining unit; SP, St. Peter aquifer

Well designation	Sample date	Hydrogeologic unit to which well is open	Boron (µg/L)	Calcium (mg/L)	Chloride (mg/L)	Iron (µg/L)	Fluoride (mg/L)	Magnesium (mg/L)	Manganese (µg/L)
21296	12-12-00	GD	16.8	85.7	10.4	1,100	¹ 0.15	37.6	41.6
21361	12-12-00	GP-GF	17.3	74.1	15.5	4,270	.16	35.4	58.5
21408	12-11-00	GD	² 12.4	82.0	12.5	1,760	¹ .14	38.4	54.1
21541	12-13-00	GF-SP	15.0	75.2	6.91	<10	.21	31.7	17.0
21615	12-13-00	GD	17.6	67.9	1.33	1,120	.25	30.3	42.4
21709	12-12-00	GP-SP	26.1	73.9	8.46	<10	.24	34.0	19.4
22336	12-12-00	GF-SP	18.0	65.1	2.66	1,640	.21	29.0	34.1
421755	12-12-00	GF-SP	² 11.9	72.4	5.11	<10	.16	31.3	106

Well designation	Sample date	Hydrogeologic unit to which well is open	Potassium (mg/L)	Silica (mg/L)	Sodium (mg/L)	Sulfate (mg/L)	ANC (mg/L)	Hardness (mg/L)
21296	12-12-00	GD	0.75	17.2	3.62	58.4	325	370
21361	12-12-00	GP-GF	1.9	13.0	2.70	67.7	265	330
21408	12-11-00	GD	.94	16.2	3.10	85.2	284	360
21541	12-13-00	GF-SP	.94	17.3	4.40	2.38	338	320
21615	12-13-00	GD	.82	17.2	5.69	1.68	322	290
21709	12-12-00	GP-SP	1.7	11.3	5.49	16.2	330	320
22336	12-12-00	GF-SP	.85	18.5	4.13	29.5	281	280
421755	12-12-00	GF-SP	.71	16.5	3.13	39.8	289	310

¹ Estimated concentration. Reporting limit is 0.16 milligram per liter.

² Estimated concentration. Reporting limit is 13 micrograms per liter.

Appendix 3. Concentrations of trace elements in ground water at selected wells in the vicinity of Belvidere, Ill., December 2000.

[All concentrations of trace elements represent dissolved fraction; µg/L, micrograms per liter; NA, not analyzed; <, less than]

Hydrogeologic unit to which well is open: GD, glacial drift aquifer; GP, Galena-Platteville aquifer; GF, Glenwood confining unit; SP, St. Peter aquifer

Well designation	Sample date	Aquifer to which well is open	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Cobalt (µg/L)	Copper (µg/L)
21296	12-12-00	GD	NA	NA	NA	NA	NA	NA	NA	NA	NA
21361	12-12-00	GP-GF	NA	NA	NA	NA	NA	NA	NA	NA	NA
21408	12-11-00	GD	4.89	0.11	¹ 0.13	52.1	<0.06	0.13	<0.80	0.20	3.40
21541	12-13-00	GF-SP	NA	NA	NA	NA	NA	NA	NA	NA	NA
21615	12-13-00	GD	NA	NA	NA	NA	NA	NA	NA	NA	NA
21709	12-12-00	GP-SP	NA	NA	NA	NA	NA	NA	NA	NA	NA
22336	12-12-00	GF-SP	NA	NA	NA	NA	NA	NA	NA	NA	NA
421755	12-12-00	GF-SP	NA	NA	NA	NA	NA	NA	NA	NA	NA

Well designation	Sample date	Hydrogeologic unit to which well is open	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)	Manganese (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Strontium (µg/L)	Thallium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
21296	12-12-00	GD	1100	NA	NA	41.6	NA	NA	NA	NA	NA	NA	NA	NA
21361	12-12-00	GP-GF	4270	NA	NA	58.5	NA	NA	NA	NA	NA	NA	NA	NA
21408	12-11-00	GD	1760	1.17	2.86	54.1	2.41	0.76	<0.33	<1.0	75.4	² 0.04	<0.21	23.5
21541	12-13-00	GF-SP	<10	NA	NA	17.0	NA	NA	NA	NA	NA	NA	NA	NA
21615	12-13-00	GD	1120	NA	NA	42.4	NA	NA	NA	NA	NA	NA	NA	NA
21709	12-12-00	GP-SP	<10	NA	NA	19.4	NA	NA	NA	NA	NA	NA	NA	NA
22336	12-12-00	GF-SP	1640	NA	NA	34.1	NA	NA	NA	NA	NA	NA	NA	NA
421755	12-12-00	GF-SP	<10	NA	NA	106	NA	NA	NA	NA	NA	NA	NA	NA

¹ Estimated concentration. Reporting limit is 0.18 microgram per liter.

² Estimated concentration. Reporting limit is 0.08 microgram per liter.

Appendix 4. Concentrations of tritium and other radionuclides in ground water at selected wells in the vicinity of Belvidere, Ill., December 2000.

[All concentrations represent dissolved fraction; pCi/L, picocuries per liter; TU, tritium units; µg/L, micrograms per liter; NA, not analyzed; <, less than]

Hydrogeologic unit to which well is open: GD, glacial drift aquifer; GP, Galena-Platteville aquifer; GF, Glenwood confining unit; SP, St. Peter aquifer

Well designation	Sample date	Hydrogeologic unit to which well is open	Tritium (pCi/L)	Tritium (TU)	Uranium-natural ¹ (µg/L)	Radium-226 (pCi/L)	Radium-228 (pCi/L)	Radon-222 (pCi/L)
21296	12-12-00	GD	44.5	13.9 +/- 0.8	NA	NA	NA	NA
21361	12-12-00	GP-GF	43.8	13.7 +/- 1.0	NA	NA	NA	NA
21408	12-11-00	GD	18.9	5.9 +/- .5	NA	NA	NA	NA
21541	12-13-00	GF-SP	< 0.1	-.3 +/- .3	NA	NA	NA	NA
21615	12-13-00	GD	1.3	.4 +/- .3	NA	NA	NA	NA
21709	12-12-00	GP-SP	13.1	4.1 +/- .4	NA	NA	NA	NA
22336	12-12-00	GF-SP	2.6	.8 +/- .3	NA	NA	NA	NA
421755	12-12-00	GF-SP	22.7	7.1 +/- .6	0.02	² NA	<1	263

¹ Natural uranium is composed of various isotopes, of which uranium-238 is predominant.

² Sample was collected, but laboratory analysis failed.

Appendix 5. Concentrations of volatile organic compounds detected in ground water at selected wells in the vicinity of Belvidere, Ill., December 2000.

[µg/L, micrograms per liter; ND, not detected; NA, not analyzed; reporting limits are 1 µg/L, except for 1,4-dioxane and tetrahydrofuran, which are 5 µg/L]

Hydrogeologic unit to which well is open: GD, glacial drift aquifer; GP, Galena-Platteville aquifer; GF, Glenwood confining unit; SP, St. Peter aquifer; OR, Ordovician aquifer system (Galena-Platteville and St. Peter aquifers); CO, Cambrian-Ordovician aquifer system (Galena-Platteville, St. Peter, Iron-ton-Galesville, and (or) Elmhurst-Mt. Simon aquifers)

Well designation	Sample date	Hydro-geologic unit to which well is open	Tri-chloro-ethene (µg/L)	Tetra-chloro-ethene (µg/L)	1,1,1-Tri-chloro-ethene (µg/L)	1,2-Di-chloro-ethene total ¹ (µg/L)	1,4-Dioxane (µg/L)	Tetra-hydro-furan (µg/L)	1,1-Di-chloro-ethene (µg/L)	1,1-Di-chloro-ethene (µg/L)	1,2-Di-chloro-ethene (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Chloro-form (µg/L)
21296	² 12-12-00	GD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
21361	12-12-00	GP-GF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
21408	12-11-00	GD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
21541	³ 12-13-00	GF-SP	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	9
21615	12-13-00	GD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
21709	12-12-00	GP-SP	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
22336	212-12-00	GF-SP	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
do.	212-12-00	GF-SP	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
421755	212-12-00	GF-SP	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGTG305GPS	⁴ 04-21-98	GP	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3	ND
do.	03-22-99	GP	ND	ND	ND	ND	NA	NA	ND	ND	ND	ND	ND	ND
do.	⁵ 12-14-00	GP	ND	ND	ND	ND	NA	NA	ND	ND	ND	ND	ND	ND
AGTG305GPD ⁶	04-20-98	GP	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
do.	03-22-99	GP	0.5	ND	ND	ND	NA	NA	ND	ND	ND	ND	ND	ND
do.	12-14-00	GP	.5	ND	ND	ND	NA	NA	ND	ND	ND	ND	ND	ND
AGTG305SP	04-20-98	SP	6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
do.	03-22-99	SP	9	ND	ND	1	ND	NA	ND	ND	ND	ND	ND	ND
do.	⁷ 12-13-00	SP	15	ND	ND	3	NA	NA	ND	ND	ND	ND	ND	ND
do.	⁸ 12-13-00	SP	14	ND	ND	2	NA	NA	ND	ND	ND	ND	ND	ND
BMW2	⁹ 03-24-99	CO	8	5	ND	1	ND	ND	ND	ND	ND	ND	ND	ND
do.	03-24-99	CO	8	5	ND	1	NA	NA	ND	ND	ND	ND	ND	ND
do.	12-15-00	CO	7	15	ND	2	NA	NA	ND	ND	ND	ND	ND	ND
BMW3	03-24-99	CO	1	5	ND	ND	NA	NA	ND	ND	ND	ND	ND	ND
do.	12-15-00	CO	1	16	ND	ND	NA	NA	ND	ND	ND	ND	ND	ND
BMW4	04-27-98	CO	ND	ND	ND	ND	ND	ND	ND	ND	1	12	ND	ND
do.	03-22-99	CO	ND	ND	ND	ND	NA	NA	0.9	ND	ND	ND	ND	ND
do.	12-15-00	CO	ND	.7	ND	ND	NA	NA	ND	ND	ND	ND	ND	ND
BMW5	04-20-98	OR	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
do.	03-23-99	OR	ND	1	ND	ND	NA	NA	ND	ND	ND	ND	ND	ND
do.	¹⁰ 12-15-00	OR	ND	.8	ND	ND	NA	NA	ND	ND	ND	ND	ND	ND
BMW6	03-23-99	CO	ND	ND	ND	ND	NA	NA	.6	ND	ND	ND	ND	.7
do.	¹¹ 12-13-00	CO	.8	ND	ND	ND	NA	NA	.6	ND	ND	ND	ND	ND
BMW7	03-23-99	CO	ND	ND	ND	ND	NA	NA	ND	ND	ND	ND	ND	ND
do.	12-15-00	CO	ND	ND	ND	ND	NA	NA	ND	ND	ND	ND	ND	ND
BMW9	03-24-99	GD	ND	ND	ND	ND	NA	NA	ND	ND	ND	ND	ND	ND
BMW9	12-15-00	GD	ND	ND	ND	ND	NA	NA	ND	ND	ND	ND	ND	ND

Appendix 5. Concentrations of volatile organic compounds detected in ground water at selected wells in the vicinity of Belvidere, Ill., December 2000—Continued.

Well designation	Sample date	Hydro-geologic unit to which well is open	Tri-chloro-ethene (µg/L)	Tetra-chloro-ethene (µg/L)	1,1,1-Tri-chloro-ethane (µg/L)	1,2-Di-chloro-ethene total ¹ (µg/L)	1,4-Diox-ane (µg/L)	Tetra-hydro-furan (µg/L)	1,1-Di-chloro-ethane (µg/L)	1,1-Di-chloro-ethane (µg/L)	1,2-Di-chloro-ethane (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Chloro-form (µg/L)
PCHG128GPS	04-21-98	GP	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
do.	03-22-99	GP	ND	ND	ND	ND	NA	NA	ND	ND	ND	ND	ND	ND
do.	12-15-00	GP	ND	ND	ND	ND	NA	NA	ND	ND	ND	ND	ND	ND
PCHG128GPD	12-04-21-98	GP	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
do.	03-23-99	GP	.5	ND	ND	ND	NA	NA	ND	ND	ND	ND	ND	ND
do.	12-14-00	GP	2	ND	ND	ND	NA	NA	ND	ND	ND	ND	ND	ND
PCHG436B	04-20-98	GP	ND	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
do.	12-14-00	GP	ND	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PCHG436GPS	04-27-98	GP	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
do.	04-27-98	GP	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
do.	12-14-00	GP	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

¹ The samples collected in 1999-2000 were analyzed for the individual isomers of 1,2-dichloroethene. Detections represent *cis*-1,2-dichloroethene.

² Analyzed 1 day beyond required maximum of 14 days from time of sampling. Values are estimated, but are considered representative of the quality of ground water near the well.

³ Also detected bromodichloromethane: 2 µg/L

⁴ Reporting limit for samples collected by the U.S. Geological Survey (USGS) in 1998 is 10 micrograms per liter (µg/L); concentrations of detected compounds less than the reporting limit are estimated. Reporting limit for samples collected by the USGS in 1999-2000 are from 1 to 5 µg/L; concentrations of detected compounds less than 1 µg/L, the reporting limit, are estimated.

⁵ Also detected tentatively identified compound, unknown: 4 µg/L (estimated)

⁶ Tentatively identified compound: unknown¹, 6 µg/L; unknown², 4 µg/L; unknown³, 6 µg/L; 9-(trimethylsilyloxy)-4-trim, 4 µg/L; unknown⁴, 5 µg/L; unknown⁵, 4 µg/L. All concentrations are estimated.

⁷ Also detected tentatively identified compound: 2-methyl-butane, 3 µg/L (estimated)

⁸ Also detected tentatively identified compound: trimethyl-silanol, 2 µg/L (estimated)

⁹ Also detected methylene chloride: 0.6 µg/L (estimated)

¹⁰ Also detected acetone: 9 µg/L

¹¹ Also detected tentatively identified compound: unknown, 6 µg/L (estimated)

¹² Tentatively identified compound: unknown, 7 µg/L (estimated)

¹³ Water sample was collected with a peristaltic pump and contained substantial air.

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